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# PROCEEDINGS
*of*
# THE INSTITUTE OF RADIO ENGINEERS

(INCORPORATED)

OFFICERS, COMMITTEES AND SUPPLEMENTARY LISTS OF MEMBERS AND ASSOCIATES OF THE INSTITUTE

THE AUDION—DETECTOR AND AMPLIFIER
DR. LEE DE FOREST

RADIO RANGE VARIATION
ROBERT H. MARRIOTT

THE INFLUENCE OF ALTERNATING CURRENTS ON CERTAIN MELTED METALLIC SALTS
C. TISSOT

THE GOLDSCHMIDT SYSTEM OF RADIO TELEGRAPHY
EMIL E. MAYER



EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED QUARTERLY BY
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NEW YORK

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# CONTENTS

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| BRADFIELD, WILLIAM W., Manager, Marconi's Wireless Telegraph Co., London, Eng.; res., 40 Albert Hall Mansion, Kensington, London, Eng. | A<br>M | May 6, 1914<br>May 22, 1914 |
| CABOT, SEWELL, Electrical Engineer, Electric Conversion Co.; res., 232 High St., Brookline, Mass. | A<br>M | Charter Member, S.W.T.E.<br>May 22, 1914 |
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| DAY, MAXWELL W., Engineer, Marine Dept., General Electric Co., Schenectady, N. Y.; res., 26 Rugby Road, Schenectady, N. Y. | A<br>M | May 6, 1914<br>May 22, 1914 |
| EDWARDS, JOHN RICHARD, Rear-Admiral, U.S.N., Navy Department, Washington, D. C. | A<br>M | Apr. 1, 1914<br>Apr. 1, 1914 |
| EWEN, HARRY A., Engineer (Chief of Design Dept.), Marconi's Wireless Telegraph Co., "Braemar," Shenfield, Essex, Eng. | A<br>M | May 22, 1914<br>May 22, 1914 |
| FULLER, LEONARD FRANKLIN, Chief Electrical Engineer, Federal Telegraph Co., San Francisco, Cal.; res., 411 Kipling St., Palo Alto, Cal. | A<br>M | May 6, 1914<br>May 22, 1914 |
| HALLBORG, HENRY E., Engineer in Charge, Marconi Trans-Atlantic Stations, New Brunswick and Belmar, N. J.; res., 220 Lincoln Ave., New Brunswick, N. J. | A<br>M | June 3, 1912<br>May 22, 1914 |
| HAMMOND, JOHN HAYS, JR., [*Treasurer*], Investigator, Hammond Radio Research Laboratory, Gloucester, Mass. | A<br>M | June 3, 1912<br>Mar. 24, 1914 |
| JANKE, ALFRED H., Technical Associate, Knight Bros., New York; res., 203 W. 9th St., Plainfield, N. J. | A<br>M | Apr. 1, 1914<br>May 22, 1914 |
| McNICOL, DONALD, Assistant Electrical Engineer, Postal Telegraph Co., New York; res., 53 Vermilyea Ave., New York. | A<br>M | Apr. 1, 1914<br>May 22, 1914 |
| STEPHENSON, LEONARD W., Engineer, Radio Service, Dominion Government, Victoria, B. C. | A<br>M | Apr. 8, 1914<br>Apr. 8, 1914 |
| WEBSTER, ARTHUR GORDON, Professor of Physics, Clark University, Worcester, Mass. | A<br>M | May 22, 1914<br>May 22, 1914 |
| WILDMAN, LEONARD D., Major, Signal Corps, U.S.A., Director, Army Signal School, Fort Leavenworth, Kan. | A<br>M | Apr. 8, 1914<br>May 22, 1914 |

## OMITTED FROM YEAR BOOK.

| | | |
|---|---|---|
| TAYLOR, CHARLES HENRY, Assistant Chief Engineer, Marconi's Wireless Telegraph Co., 233 Broadway, New York. | A<br>M | Nov. 5, 1913<br>Nov. 5, 1913 |

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ARRANGED ALPHABETICALLY.

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| | |
|---|---|
| BARRETT, HOWARD A., Instructor, Barrett's School of Telegraphy; res., 343 East 152nd St., New York. | Apr. 15, 1914 |
| BEAKES, WILLIAM E., Chief Engineer, Tropical Radio Telegraph Co., 321 St. Charles St., New Orleans, La. | May 6, 1914 |
| BICAK, EDWARD THOMAS, Radio Telegrapher, Marconi Wireless Telegraph Co., New York; res., 357 E. 72nd St., New York. | Apr. 22, 1914 |
| BROWN, EDWARD H., Student, Shaw High School; res., 2208 Harcourt Drive, Ambler Heights, Cleveland, Ohio. | Apr. 22, 1914 |
| BROWN, ROLLA, Clerk, Dept. Carriers' Accounts, U. S. Interstate Commerce Commission, Washington, D. C.; res., 509 Rhode Island Ave., N.E., Washington, D. C. | Apr. 1, 1914 |
| CARR, STEPHEN C., Student, College City of New York, New York; res., 18 West 96th St., New York. | Apr. 22, 1914 |
| CAROLIN, ROBERT, Electrical Assistant, U. S. Signal Corps, New York; res., 100 East 34th St., New York. | Apr. 1, 1914 |
| CHAMBERLAIN, E. T., Commissioner of Navigation, Department of Commerce, Washington, D. C. | Apr. 15, 1914 |
| CLAYTON, ROYAL S., Radio Operator, National Electric Signaling Co., New York. | Apr. 8, 1914 |
| COCKADAY, Lawrence M., General Secretary, Cathedral Choir School; res., 227 Audubon Ave., New York. | Apr. 15, 1914 |
| COHEN, WALTER A., Draughtsman, Keller Mechanical Engineering Co., New York; res., 2071 Fifth Ave., New York. | Apr. 22, 1914 |
| CONLEY, CHARLES B., Telephone Operator, Pennsylvania R. R.; res., 709 N. 39th St., Philadelphia, Pa. | Apr. 15, 1914 |
| CONNER, GEORGE W., Engineer, 18 Sheldon St., Roslindale, Mass. | Apr. 22, 1914 |
| COOPER, CHARLES B., Chief Operator, Northern Division, Marconi Wireless Telegraph Co., Seattle, Wash.; res., 738 19th Ave., N. Seattle, Wash. | May 22, 1914 |
| COWPER, NORMAN CLAIR, Electrician, Lynbrook, L. I., N. Y. | May 22, 1914 |
| CREASER, ISAIAH, Electrician, Narragansett Electric Light Co., Providence, R. I.; res., 8 Alfred St., Providence, R. I. | May 6, 1914 |
| CRESSY, LOUIS A., Electrician, 104 Huntington St., Hartford, Conn. | May 22, 1914 |
| DALY, THOMAS J. M., Gulf Compress Company, Memphis, Tenn. | May 6, 1914 |
| DANE, FRANCIS W., Radio Operator, Tropical Radio Telegraph Co.; res., Main St., Hamilton, Mass. | Apr. 15, 1914 |
| DROSTE, GEORGE I., Draughtsman, Thompson-Starrett Co.; res., 1309 Pugsley Ave., Bronx, New York. | Apr. 22, 1914 |
| DUDLEY, DEWITT CLINTON, Constructing Engineer, Radio Apparatus Co., Philadelphia, Pa.; res., 3916 Market St., Philadelphia, Pa. | Apr. 15, 1914 |

DUVALL, EDWARD B., Radio Experimenter, 809 Park Ave., Baltimore, Md. — Apr. 1, 1914

EAVES, AUGUSTUS J., Telegraph Engineer, Postal Telegraph Cable Co.; res., 506 W. 113th St., New York. — Apr. 1, 1914

EMMERSON, FRANK, Student, Portsmouth High School; res., 419 High St., Portsmouth, Va. — May 22, 1914

ESTEY, F. CLIFFORD, Electrician, National Calfskin Co.; res., 22 Oakland St., Salem, Mass. — Apr. 15, 1914

EVANS, LOUIS M., Electrical Engineer, Signal Corps, U.S.A., Washington, D. C.; res., 408 N. Alfred St., Alexandria, Va. — Apr. 1, 1914

FERRIS, MALCOLM, Student, Electrical Engineering, Haverford College; res., 3409 Baring St., Philadelphia, Pa. — May 22, 1914

FISCHER, GEORGE H., JR., Radio Operator, Marconi Wireless Telegraph Co.; res., 5423 Baltimore Ave., Philadelphia, Pa. — Apr. 15, 1914

FITE, THOMAS A., Manager, Berkeley Radio Laboratories, Berkeley, Cal. — Apr. 22, 1914

FITLER, EUGENE B., JR., Clerk, Electrical Products Co.; res., 40 West 129th St., New York. — May 22, 1914

FLEISS, ROBERT ANTON, Master Signal Electrician, Company A, 1st Aero Squadron; res., 99 Claremont Ave., New York. — Apr. 1, 1914

FOLEY, LEWIS B., Superintendent, Telegraph, Telephone & Wireless Department, D., L. & W. R. R. Co., New York; res., Denville, N. J. — Apr. 1, 1914

FOWLER, HARRY A., Editor, 17, Board of Trade, Kansas City, Mo. — Apr. 22, 1914

FREEMAN, WALTER CLARKSON, Engineer, Stromberg Carlson Telephone Mfg. Co.; res., 49 Darwin St., Rochester, N. Y. — Apr. 1, 1914

GEARE, GEORGE A., Mechanic, General Electric Co.; res., 23½ Cottage St., Jersey City, N. J. — Apr. 1, 1914

GIFFIN, SIDNEY H., Student, Baltimore Polytechnic Institute; res., 2614 North Calvert St., Baltimore, Md. — Apr. 15, 1914

GODLEY, Paul F., Radio Inspector, Brazilian Government, res., Leonia, N. J. — May 6, 1914

GOGEL, ADELBERT J., Designer, Gogel Manufacturing Co.; res., 628 S. Erie St., Toledo, Ohio. — May 22, 1914

HALL, THOMAS C., Engineer, Pacific Wireless Equipment Co.; res., 1278 Market St., San Francisco, Cal. — Apr. 22, 1914

HALLER, GEORGE F., Vice-President, Haller-Cunningham Electric Co., San Francisco, Cal.; res., San Mateo, Cal. — Apr. 22, 1914

HANCE, SPENCER W., Superintendent, Radio Service, Vaccaro Bros. & Co., New Orleans, La. — Apr. 1, 1914

HART, M. EMANUEL, General Manager, Gulf Radio Co., 407–21 Baronne St., New Orleans, La. — May 6, 1914

HENDERSON, JOHN C., Operator of Wireless Telegraphy Station, Shortridge High School, Indianapolis, Ind.; res., 1659 Central Ave., Indianapolis, Ind. — May 6, 1914

HITT, PARKER, Capt., Signal Corps, U.S.A., Instructor, Army Signal School, Fort Leavenworth, Kansas; care Chief Signal Officer, Washington, D. C. — Apr. 8, 1914

HOGGER, CHARLES, Inspector, Russian-American Line, res., 471 41st St., Brooklyn, N. Y. — Apr. 1, 1914

HOPPOCK, ALLEN H., Student, New York University; res., 215 Clark St., Westfield, N. J. — Apr. 22, 1914

INWRIGHT, JOHN A., Student, New York University; res., 400 H. Fairmount Ave., Jersey City, N. J. — Apr. 15, 1914

JOHNSON, THEOPHILUS, JR., Draftsman, City of New York; res., 17 Third St., Woodside, L. I., N. Y. — May 6, 1914

KELLEY, GEORGE W., JR., Operator, Marconi Wireless Telegraph Co.; res., 1738 N. 16th St., Philadelphia, Pa. — Apr. 15, 1914

KELLEY, WILLARD S., Master Signal Electrician, Signal Corps, U.S.A., Washington, D. C. — Apr. 8, 1914

KINGSBURY, KENNETH, 24 Chestnut St., Binghamton, N. Y. — Apr. 15, 1914

KNOTTS, HARRY J., Experimenter, and Publisher of "The State Center-Record," Illiopolis, Ill. — May 6, 1914

LACHAPELLE, JACQUES DE, Student, The College of the City of New York; res., Highwood, N. J. — Apr. 15, 1914

LAMB, EDWIN S., Instructor, Kenosha Wireless School; res., 119 Milwaukee Ave., Kenosha, Wis. — Apr. 22, 1914

LANE, DAVID M., Electrical Engineering Student, Cooper Union; res., 343 Ninth St., Jersey City, N. J. — May 6, 1914

LEISTER, FAYETTE, Student, Drexel University, West Philadelphia, Pa.; res., 68th and Jefferson Sts., West Philadelphia, Pa. — Apr. 15, 1914

LITTLEFIELD, CHAS. I., 2662 East 24th St., Sheepshead Bay, N. Y. — Apr. 15, 1914

MACLELLAN, LESLIE W., Radio Operator, National Electric Signaling Co., Brooklyn, N. Y.; res., 11 Myron Ave., New Haven, Conn. — May 6, 1914

MANUEL, FLOYD, Post Office Clerk, U. S. Post Office Dept.; res., 106 Second St., Newport, R. I. — Apr. 22, 1914

MARTIN, DELOSS K., Student, Polytechnic College; res., 1459 Harrison St., Oakland, Cal. — May 22, 1914

MCKNIGHT, W. ROSS, Advertising Man, International Correspondence School; res., 243 Jefferson Ave., Scranton, Pa. — May 6, 1914

NENNSBERG, ALEXIS A., Chief of the Radio Station, "Kerbinskaja," Russian Government; res., Kerby, Nikolajevsk Primorsky, Russia. — Apr. 1, 1914

OGG, GLEN ROY, Chief Radio Electrician, U.S.S. "Nebraska"; care Postmaster, New York. — May 22, 1914

OXNER, EDWIN K., Radio Operator, Marconi Company, Boston, Mass.; res., 5 Oakman St., Dorchester, Mass. — Apr. 8, 1914

PARKER, JAMES F., Cable Clerk, New York Railways Co.; res., 113 East 75th St., New York. — Apr. 1, 1914

PELHAM, FRED B., Motion Picture Operator, Hiawatha Theatre, Washington, D. C.; res., 603 Howard Place, N.W., Washington, D. C. — Apr. 22, 1914

PICKERILL, ELMO NEALE, Instructor, Marconi Wireless Telegraph Co. of America, New York; res., 248 West 46th St., New York. — Apr. 1, 1914

| | |
|---|---|
| POWELL, EDWIN L., Topographic Draftsman, U. S. Geological Survey, Washington, D. C.; res., 1206 E. Capitol St., Washington, D. C. | Apr. 22, 1914 |
| PRASTKA, ANTHONY, Gunner (Radio Duty), U.S.N., U.S.S. "New York"; care Postmaster, New York. | Apr. 1, 1914 |
| PRATT, HARADEN, Student, University of California; res., 1510 Lombard St., San Francisco, Cal. | Apr. 1, 1914 |
| REDE, G. ROSS, Radio Experimenter, 210 W. Madison St., Baltimore, Md. | Apr. 22, 1914 |
| REINHARD, CYRIL DEWITTE, in Charge of United Fruit Co.'s Radio Station, Santa Marta, Republic de Colombia, South America. | May 22, 1914 |
| RICE, REGINALD K., Construction Engineer, Marconi's Wireless Telegraph Co., Ltd., Strand, London, W.C., England; res., The Nutshell, Cheam Road, Sutton Surrey, England. | May 22, 1914 |
| RINGGOLD, PAUL C., Stenographer, Marconi Wireless Telegraph Co.; res., 606 St. Ann Ave., Baltimore, Md. | Apr. 1, 1914 |
| SADENWATER, HARRY, Instructor, East Side Y. M. C. A., New York; res., 740 Herman Place, New York. | Apr. 15, 1914 |
| ST. JAMES, ROBERT T., Electrician, Mahaiwe Theatre, Great Barrington, Mass.; res., Great Barrington, Mass. | May 22, 1914 |
| SANTOS, ANTHONY SILVA, Clapp-Eastham Co., Cambridge, Mass. | Apr. 1, 1914 |
| SEIBERT, LAWRENCE W., Electrical Assistant, U. S. Signal Service, New York; res., 34 Benton St., Trenton, N. J. | Apr. 15, 1914 |
| SMITH, MALCOLM H., Student, Lowell Textile School; res., 115 Prospect St., Gloucester, Mass. | May 6, 1914 |
| SNYDER, NORMAN G., President, Ithaca Communication Club; res., 214 University Ave., Ithaca, N. Y. | Apr. 15, 1914 |
| SPRADO, HUGH RALPH, Radio Engineer, Federal Telegraph Co.; res., 911 Grand St., Alameda, Cal. | May 22, 1914 |
| STANLEY, LYMAN ROBERTS, Treasurer, The Stanley Co.; res., 52 Burrill St., Swampscott, Mass. | May 22, 1914 |
| STEINER, CHARLES I., Student of Engineering, Columbia University, New York; res., 596 Jackson Ave., Long Island City, N. Y. | May 6, 1914 |
| STEVENS, THOMAS M., Superintendent, Eastern Division, Marconi Wireless Telegraph Co., Boston, Mass.; res., Watertown, Mass. | Apr. 1, 1914 |
| STONE, ELLERY W., Student, University of California; res., 317 Lee St., Oakland, Cal. | Apr. 22, 1914 |
| TAYLOR, JAMES B., Capt., Coast Artillery Corps, U.S.A., Director, Coast Artillery School, Fort Monroe, Va. | Apr. 8, 1914 |
| THOMPSON, VANCE, Student, Memphis University School; res., 267 Pasadena Place, Memphis, Tenn. | Apr. 22, 1914 |
| TRENOR, ALBERT D., Assistant Engineer, John Hays Hammond, Jr., Gloucester, Mass.; res., 142 East 62nd St., New York. | Apr. 1, 1914 |
| TROGNER, ARTHUR M., Radio Draftsman and Tester, Machinery Division, Philadelphia Navy Yard; res., 1211 Locust St., Philadelphia, Pa. | Apr. 1, 1914 |
| TURNER, HUBERT M., Instructor, Electrical Engineering, University of Minnesota; res., 719 Erie St., S.E., Minneapolis, Minn. | May 6, 1914 |

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|---|---|
| UNDERHILL, CHARLES R., Chief Electrical Engineer, Acme Wire Co., New Haven, Conn.; res., 84 Stanley St., New Haven, Conn. | Apr. 8, 1914 |
| VANSIZE, WILLIAM BALDWIN, Patent Expert, Marconi Wireless Telegraph Co., New York; res., 181 Woodruff Ave., Brooklyn, N. Y. | Apr. 22, 1914 |
| WAGGONER, CHAUNCEY W., Professor of Physics, West Virginia University, Morgantown, W. Va.; res., 727 N. Front St., Morgantown, W. Va. | May 22, 1914 |
| WATTS, FELIX J., Radio Engineer, University of Michigan, Ann Arbor, Mich.; res., 318 N. Ingalls St., Ann Arbor, Mich. | May 6, 1914 |
| WASHINGTON, BOWDEN, Tester, Clapp-Eastham Co.; res., The Ludlow, Trinity Place, Boston, Mass. | Apr. 1, 1914 |
| WERTHER, ARTHUR G., Wireless Apparatus Manufacturer; res., 1514 76th St., Bath Beach, Brooklyn, N. Y. | Apr. 1, 1914 |
| WILDE, PHILLIPS B., Assistant Engineer, U. S. Light House Service, Dept. of Commerce; res., Woods Hole, Mass. | Apr. 15, 1914 |
| WOODWARD, RAYMOND W., Student, Trinity College, Hartford, Conn.; res., 14 Tremont St., Hartford, Conn. | May 22, 1914 |
| WORRALL, JOSEPH ALLEN, Radio Operator, Marconi Wireless Telegraph Co.; res., 163 Logan St., Brooklyn, N. Y. | Apr. 1, 1914 |
| WYBLE, JAMES F., Construction Engineer, Marconi Wireless Telegraph Co., Baltimore, Md.; res., 2743 Harlem Ave., Baltimore, Md. | May 22, 1914 |
| ZINSZER, HARVEY A., Inspector, Consolidated Telephone Co.; res., 920 South 6th St., Allentown, Pa. | Apr. 22, 1914 |

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| | |
|---|---|
| KNOLL, LLOYD M., Instructor in Physics, Central High School; res., 3260 Chestnut St., Philadelphia, Pa. | Oct. 15, 1913 |
| WRIGHT, GEORGE B., Lieut., U.S.N., Assistant Radio Officer, Bureau of Steam Engineering, Navy Department, Washington, D. C. | Mar. 12, 1913 |

## SUMMARY OF MEMBERSHIP

June 1, 1914.

| | |
|---|---|
| MEMBERS | 79 |
| ASSOCIATES | 311 |
| Total | 390 |

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It is requested that *changes of address* be forwarded promptly to:

THE SECRETARY, INSTITUTE OF RADIO ENGINEERS,

71 Broadway, New York.

# THE AUDION—DETECTOR AND AMPLIFIER *

By Dr. Lee De Forest

*Past-President, Society of Wireless Telegraph Engineers*

Notwithstanding the now wide-spread use of the Audion as a detector in radio telegraph and telephone service few accounts of independent research into the nature of this instrument, or even cursory descriptions of its operation, seem to have been recorded, since the original paper presented before the American Institute of Electrical Engineers in 1906.

At that time, pending patent applications prevented the presentation of a detailed description of certain forms and improvements which are to-day common knowledge among radio engineers. It is my purpose herein to outline briefly the subsequent development of the Audion, both as a radio detector and as an amplifier of minute electric impulses.

For the benefit of those not familiar with radio detectors a brief description of the Audion follows:

A small incandescent lamp bulb is provided with a tantalum filament F (Figure 1), operated at from 4 to 15 volts. There is mounted close to one side of this filament, and parallel to its plane, a small plate of nickel, W. This plate is connected thru a telephone receiver, or other indicating device, R, with the positive terminal of a number of dry cells, B, arranged to give from 15 to 40 volts by the use of a multi-point switch. The negative terminal of this battery is connected to one side or terminal of the filament, which latter is lighted from a suitable storage battery, A.

Between the filament and the plate is mounted a third electrode, G, usually in the form of a grid-shaped wire, or a perforated plate. Approximately 1/16th of an inch (1.5 mm.) separates the grid from the plate on one side, and from the filament on the other.

In Figure 4, a regular commercial Audion receiver set, with its bulbs and adjusting switches, is shown. The two bulbs are mounted in an inverted position in order that the heated filaments do not sag into contact with the grid and their supporting wires after prolonged use. The plates of these bulbs are clearly visible.

* Delivered before The Institute of Radio Engineers, December 3, 1913.

Figure 1

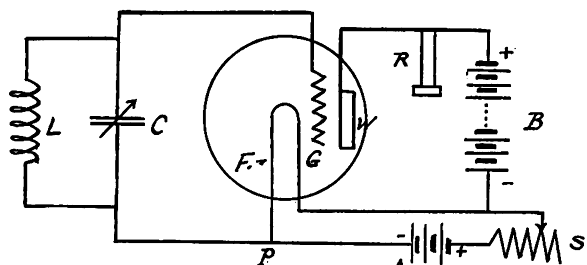



Figure 2

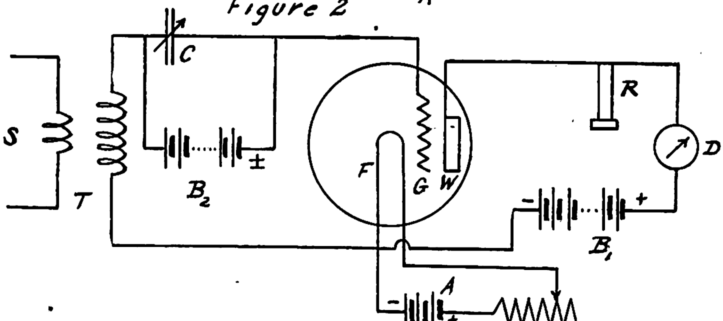
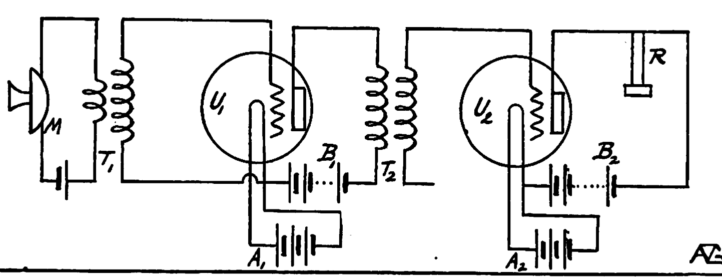



Figure 3



From the protected lower ends of these bulbs the terminal wires of the grid and plate pass out. The top three-point switch places either of the Audions in circuit. The center rotary switch inserts more or less resistance in the "A" battery circuit. The lower nine-point switch enables the insertion of extra batteries in the "B" battery circuit; these batteries being inserted in sets of three at a time.

When used as a detector, this grid electrode is connected to one terminal of the source of received radio frequency oscillations, the other terminal being connected to the Audion filament at P.

In the unlighted bulb, the resistance between the electrodes is practically infinite. When the filament is at white heat, a resistance of from 10,000 to 30,000 ohms is found between it and the cold anode. The value of this resistance depends upon a variety of conditions; such as filament temperature; size, shape, condition and location of the two outside electrodes; amount of electromotive force impressed on the gas; degree of vacuum; nature and degree of purity of the gas; magnetic forces to which the ions are subjected; *and the instantaneous value and sign of the electric potential impressed, or residing, on the intermediate, or grid, electrode.*

The introduction within the exhausted bulb of this third electrode (preferably, but not necessarily, located between the filament and the anode plate) at once placed the Audion in a distinct class, both as to sensitiveness when used as a responsive radio detector, and also as to its mode of operation. No longer, by any form of argument, could the grid Audion be classed as a rectifier, or "vacuum valve." Attempts to confuse it with the so-called Fleming "valve tube" have, I believe, failed to convince any one who has actually compared these two detectors, when each is properly constructed and connected. The difference observed in their operation is more than merely one of degree.

The vacuum valve, as first discovered by Edison, and carefully studied by Elster and Geitel*, has most marked rectifying properties, excelling in efficiency any electrolytic or crystal rectifier.

In this original device the cold electrode (or electrodes), was connected to the positive terminal of the filament. It was itself subjected to what may be, under favorable conditions, a very energetic bombardment of negatively charged corpuscles from the negative portions of the filament, while itself giving off prac-

* Wiedemann's Annalen, XVl, 1882.

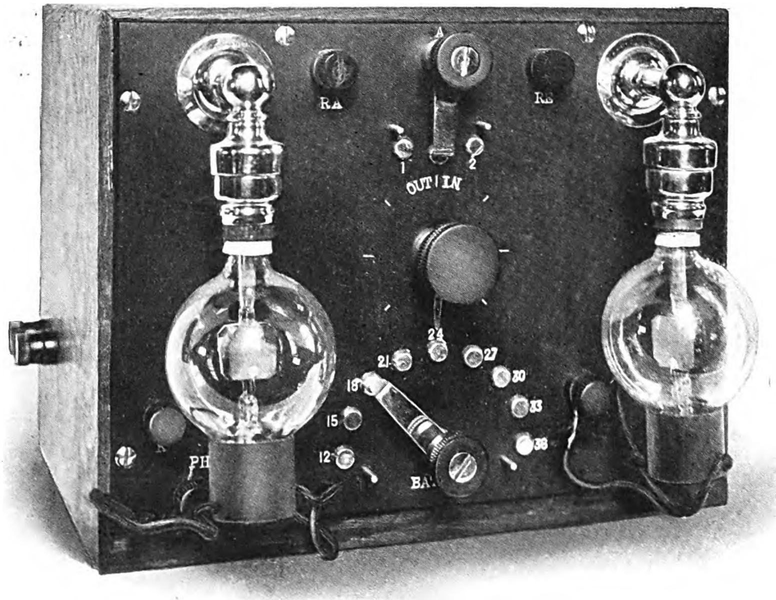



FIGURE 4—Audion Receiver.

tically no negative carriers. This valve rectifies small currents of any frequency, and can therefore be used in connection with a continuous current galvanometer to detect and measure the half-oscillations impressed on a tuned radio frequency transformer, the secondary terminals of which are connected to the anode plate and to one end of the filament respectively.

Starting from my experiments with the rectifying qualities of a gas flame (where the sources of heat energy and of the impressed e. m. f. across the electrodes were distinct and separate), the writer early found that if this incandescent-filament vacuum-rectifier were provided with a second battery, of proper voltage, independent of the lighting source and connected between one leg of the filament and the plate, (which plate must *always* be made the anode); then the device became more than a simple rectifier.

It took on the nature of a true detector, a "wave-responsive" device. In other words, it became to a degree a "trigger" tube, a genuine *relay*, giving responses in the indicating instrument (which was now preferably the telephone receiver) of considerably greater intensity than could be had from the received currents simply rectified. The regular and steady departure of negative ions, or carriers, from the cathode under stress of the "B" battery was found subject to sudden and great variations, following the variations of the applied radio-frequency e. m. f.; the degree of sensitiveness depending, for any given bulb, upon the heat of the filament and the amount of this applied "B" battery voltage.

At once the old vacuum valve took rank in sensitiveness with the electrolytic detector, until that time the most sensitive known.

The next step in advance was, as above stated, the introduction of the electrical impulses into the gaseous medium by means of a third and independent electrode.

This grid and filament, connected across the condenser of a receiving circuit, adds a slight capacity and a very high resistance shunt to that condenser. The additional damping thus introduced in the oscillating circuit is excessively small, its resonant qualities are unimpaired. The Audion thus lends itself, far more than any other form of energy-transforming detector, to sharp tuning. I have found properly designed receiving circuits equally sharply tuned, whether the Audion or the make-and-break contact detector (Poulsen tikker) be used therewith.

There appears to be no lower limit of sensitiveness to the Audion, no minimum of suddenly applied e. m. f., below which

the received impulses fail to produce any response. The exciting impulse, it is true, may be be too minute to cause a directly discernible effect in the "B" circuit, but if this effect be amplified through one or more steps, as will be hereafter described, the effect of the original excitation is found to exist.

Even in this day of universally accepted long-distance "wireless records," it is difficult for those who have not actually used the Audion detector to believe some of the receiving feats which are scored to its credit.

The Audion has the further advantage of entire absence of adjustment in the receiver itself. If the two battery potentials are once properly adjusted it requires no further attention. There is no fatigue under any conditions of use. A powerful spark discharge in close proximity may cause the "blue arc," or visible cathode discharge, to pass, but after a second or two this "paralysis" will automatically disappear, while a high resistance path (of the order of several megohms) between plate and grid will generally prevent this blue arcing.

This is therefore a suitable detector to use with a telegrapher's "breaking key." If a key-actuated relay be arranged to open the filament circuit with each depression of the Morse key, the Audion is always ready to catch the distant operator's call, or attempt to "break" in the midst of a message. On the other hand, the sensitiveness of the electrolytic and that of the best of the crystal detectors is frequently destroyed by one violent impulse, unless protected by shunting and disconnecting switches.

If there is any justification in the attempt to classify radio detectors as "current-operated" or "potential-operated" devices, there can be not the slightest hesitancy in classing the Audion as a potential-operated detector. Obviously it is in no sense a contact device, perfect or imperfect. Its response is strictly quantitative, up to the critical point of the voltage-response curve where "saturation" of ions or gas carriers begins. Up to that critical point the change in current passing from plate to filament is essentially proportional to the voltage applied to the grid electrode.

This voltage may be merely that of the hand discharging into the grid. When the lead to this grid is suddenly grasped, a click may be heard in the telephone receiver in the "B" circuit. If the charge thus impressed upon the grid be negative a repulsion or scattering of the negatively charged carriers emanating from the filament occurs. If the impressed charge be positive, then

these carriers may be attracted to the grid and discharged there, or delayed in the neighborhood. In either case, therefore, a diminution in the number of ions reaching the plate results, and we observe a diminution in the deflection of a sensitive milliameter or galvanometer in the "B" circuit when a prolonged series of impulses is delivered to the grid. The normal current is usually of the order of a milliampere, and its response diminution may vary from an undiscernible amount to 50 or even 90 per cent. of its full value.

An insight into what forces are at work in the Audion is afforded by experiments with a special circuit, such as that shown in Figure 2. When a negative charge is applied to the grid a click is heard in the telephones. When a positive charge is applied, almost no sound is heard. If G is negatively charged to 20 volts, while a sound from telephonic currents from source S is being received, the sensitiveness of the Audion is practically annulled. When G is positively charged the sound is greatly reduced, but not to the foregoing extent. This experiment seems to show that in the normal operation of the Audion the imposition of a charge, negative or positive, upon the grid acts either to repel from its neighborhood the ionic carriers or to hold them idle there, thus in either case increasing the effective resistance in the filament-to-plate path.

The first establishment of the ionic circuit of an Audion when the filament is suddenly lighted is perfectly silent—no sound is heard in the telephone, altho a galvanometer in series shows that the "make" is practically instantaneous. The establishment of the gaseous conductivity is sufficiently gradual, however, to make no sound. I do not know of any similar rapid circuit-closing device which is thus silent. While this "B" current assumes nearly its maximum amplitude practically instantly, its full value may not be reached for several seconds. A slow and irregular creeping of the milliameter needle reveals how gradually the ions adjust themselves to a completely stable condition. Upon the rupture of the filament circuit, however, the "B" circuit opens practically instantly, invariably accompanied by a click in the receiver telephone.

Referring again to the arrangement in Figure 2: when the grid is positively charged, the voltage of $B_2$ made nearly equal to that of $B_1$, and the heating current carefully adjusted, a very intense whistling note may be obtained in the telephone receiver, loud enough to be heard a meter from the instrument.

The pitch of this note slowly rises to a maximum, at which it remains for some time. A higher voltage at $B_2$ (18 volts) gives a higher initial pitch, which also increases to a maximum. The tone produced is a very pure sound. This note will sometimes increase from a very low to an extremely shrill pitch, then drop again down the scale, and suddenly cease.

Such siren effects with this circuit are always transient and critical, and are usually obtained only when the blue glow is visible to the eye. The effect is not dependent on the presence of the condenser C, but a high impedance on the $B_1$ circuit is essential. An impedance in the $B_2$ circuit aids the phenomenon. When the grid is negatively charged the Audion cannot be made to whistle. Its sensitiveness is nil, and if this $B_2$ voltage is made large enough the current thru the $B_1$ circuit is completely cut off.

These siren phenomena are probably due to the alternate effect of the suddenly altering positive charge of the grid on the positive charge of the plate, and vice versa; i. e., to the reaction of the two circuits upon each other thru the coupling medium: the gas path in the bulb. The gradual increase of pitch observed may be due to the gradual increase in the intensity of the cathode discharge, which increase would take place, without the presence of the positive charge on the grid, very suddenly, but is now greatly retarded by the disturbing reciprocal action of the two charging circuits. When a stable state, or pitch, is reached, the ensuing decrease of pitch may be due to the rapid running down in voltage of the small dry cells used, until the voltage across the gas is again reduced below the critical "blue arc" stage, whereupon the phenomenon ceases. These siren effects are not found with every bulb.

Even when the grid is uncharged an Audion can be made to give out a loud piercing whistle if a magnet be held in the proper position nearby. The pitch of this note may now be found to decrease as the "B" voltage is raised. Considerable impedance, but no condenser, is necessary to obtain these effects, showing that we are not dealing here with ordinary oscillating-circuit phenomena, where the frequency is proportional to the square root of the product of inductance and capacity.

My experiments with tungsten and other filaments, and with platinum filaments coated with alkali metals or salts, and with various gases or vapors in the bulb, have not shown any method of increasing the sensitiveness obtained with tantalum as a filament and with atmospheric air exhausted to the most effective pres-

sure. The best value of "B" potential required to produce maximum sensitiveness depends on the degree of vacuum, being roughly proportional to the degree of exhaustion.

An interesting phenomenon is observed in certain bulbs where the "B" voltage is adjusted until a sheaf of visible blue cathode rays spreads out, fan-like, from around the edge of the plate. Then, when powerful impulses are received on the grid a momentary flaring out of this blue aura can be observed with each signal, so that it is possible to read the telegraph signals directly by sight. This effect has been observed at radio receiving stations separated many miles from the transmitter.

For radio telephony, whether in true radio service, or in the so-called "wired wireless," the Audion is practically the only suitable receiver. Its extraordinary sensitiveness, its reliability, and perfectly *quantitative* response have earned for it a general recognition, abroad as well as here. The range of communication is easily increased by 50 to 100 per cent over that possible with the crystal or electrolytic detectors.

## THE AUDION AS AMPLIFIER.

In a patent issued to the author in 1907 is described an arrangement whereby a grid Audion can be so connected that it acts as a relay and also amplifies minute pulsating electric impulses. Of late this amplifier has been much studied and is now being applied to a variety of purposes.

Figure 3 shows the simplest arrangement using two amplifiers "in cascade." The source of energy to be amplified may be an Audion used as a radio-detector, a microphone, a magneto telephone receiver over a long distance line, a cable transmitter, or the like. $T_1$ represents a step-up transformer, which is essential if the impulses from S be of low voltage.

For a single amplifier, $T_2$ will represent the indicating instrument. For a two-step amplification, $T_2$ is a one-to-one transformer. Where the two amplifiers are supplied from separate lighting batteries $T_2$ may consist of one coil only. Similarly amplifier Number 2 may actuate a third, and so on; the successive steps requiring, as a rule, larger bulbs, with larger heating areas and larger cold electrode surfaces.

The assembled three-step amplifier is shown in Figure 5. The switches for adjusting "B" battery voltage and "A" battery circuit resistance, and for throwing the bulbs on or off are clearly

visible. It will be seen that the apparatus has been arranged so that a single bulb can be used, or a two or three-step amplification as may be desired.

By measurements made with the shunted-telephone-receiver method, a good Audion amplifier shows an amplification of 500 per cent. This general ratio holds also for the second and third steps, so that with three Audion amplifiers in cascade I have obtained an energy amplification of one hundred and twenty times, and this including losses from the three transformers in circuit.

The strictly quantitative action above described holds for the hundred-fold, three-step amplifications as well; so that the ear at least, detects no distortion in this process. This holds unless the third amplifier is over-excited, so that the "blue arc" passes. This latter effect can always be prevented, as above explained, even while relatively large current variations are registered. To what limits of amplification this Audion principle can be carried has not yet been determined.

The principle involved differs so radically from that of any form of telephone, microphone, or mechanical amplifying device that the Audion opens up entirely new possibilities in all lines of micro-electrics. First of all, its extraordinary sensitiveness is attended with no delicate adjustments and is absolutely non-microphonic. No amount of jarring or mechanical vibration disturbs its complete reliability. The ticking of a watch placed upon an ordinary microphone connected with one dry cell in a primary current can be amplified and heard thru a telephone when a coupling of less than five per cent unites the microphone circuit with the amplifier-telephone circuit; whereas from the most sensitive telephone receiver connected directly in this secondary circuit not a trace of a sound can be heard. Thus any microphone, or *even an ordinary magneto receiver*, with a two- or three-fold amplifier becomes a "Dictograph"—but with a delightful clearness of articulation.

If, in the radio telephone receiver, we add one or two amplifiers to the usual Audion detector, it is possible to bring up, clear and loud, articulation which, with this detector and telephone receiver alone, is too faint to understand. Similarly with the radio telegraph. The amplifier when used to relay the signals received on the Poulsen tikker at San Francisco has postponed by two hours the time of "daylight fading" from Honolulu.

The current changes in the circuits of the second or third amplifier are sufficient to operate reliably a moderately sensitive contact relay; so that it is now possible to operate any desired

form of calling device, or remote control apparatus, by any radio signals which are clearly audible, as well as to read easily signals which are quite inaudible with the ordinary detectors.

Inasmuch as a theoretically perfect single rectifier can have an efficiency of only 50 per cent., the fact that the Audion, amplifying alternating currents of practically any frequency, shows an efficiency of from 100 to 500 per cent., should most effectively silence the old and recurrent contention that this detector is merely a sensitive and efficient rectifier, or "vacuum valve."

In the long-distance telephone field lies the most obvious and useful application of this amplifier. The Audion used as a two-way amplifier at the middle of a metallic circuit requires, it is true, some type of the usual balanced circuits, with precautions to prevent "singing"; but the difficulties here afforded are less serious than with the microphone-telephone repeater. The relative constancy of adjustment, and especially the freedom from microphonic troubles and distortion, simplify the problem. It is the writer's hope that more detailed information of exceedingly interesting work which is being done in this direction by telephone engineers may shortly be presented.

Aside from long distance work, other applications of this telephone relay, of more radical and far-reaching significance, may be produced in the future. For example, it has been suggested that a magneto telephone receiver be used in place of the microphone at each subscriber's station, allowing once more that original clearness and fidelity of voice which was sacrificed when the microphone was made a part of every telephone equipment. No central battery energy need be supplied to the subscriber, except for calling purposes. His voice supplies the energy for driving this magneto dynamo. The minute, but correct, currents thus generated might be carried to central station over a pair of wires of such size that twice the present number of conductors could be inclosed in the standard sized cables. With these minute currents, troubles from cross-talk would be minimized, while high resistance or microphone contacts in the lines would cease to be the serious matters they are at present. The Audion, being an extremely high-resistance device, requires for a transformer a high-resistance primary, with a secondary adapted to standard telephone receivers.

At the central stations, then, we would have banks of Audion amplifiers fed from the common storage battery. In-coming and out-going calls would operate signal devices with this central battery energy as at present, but when the talking circuit was

made, the subscriber's magneto transmitter would be connected, thru an induction coil, to the grid of an idle Audion, amplified, sent out over a trunk line, re-amplified, if necessary, at the other exchange, transformed, and sent out to the receiver's station.

## THE AUDION AMPLIFIER IN CONNECTION WITH THE TELEGRAPHONE.

The ease with which voice records are made on the fine steel wire of a Telegraphone, the fidelity of these records (when not intense enough magnetically to saturate the wire), and the practically unlimited length of a record (30 minutes or more), once appeared to give to this wonderful device possibilities which were quite beyond any to be hoped for from the cylinder or disk phonograph. However, the faintness of the reproduction has limited the commercial application of the Telegraphone to an office dictating and telephone-recording machine. All attempts reliably to amplify Telegraphone records so as to throw the sound out into a room, by the use of microphone relays, have failed. The adjustments are too delicate and transient, and the distortion excessive.

With a three-step Audion amplifier I am able to supply a number of "loud-speaking" telephone receivers, and to distribute music, or voice records, over a small hall in sufficient volume. From four such loud-speaking receivers nested together, a violin record on the Telegraphone has been heard at a distance of 250 feet in quiet open air. By the use of larger bulbs for the third amplification, and with two or more of these in parallel, each supplying six or more loud-speakers, any enclosed space of reasonable size can be filled.

This amplification of Telegraphone records has revealed a number of interesting peculiarities of that instrument hitherto unrealized. Notably it has shown how imperfect and unreliable a device is the carbon microphone, voice actuated. The haphazard action of packing, friction, and the effect of the natural vibration periods of the diafram, are exasperatingly demonstrated. I am at work on these problems at the present time, investigating the best methods for recording various types of music, voice, etc., and using for this purpose both the microphone and special forms of magneto transmitters. I believe the application of the Telegraphone to the music-reproduction field now awaits a perfection of proper methods of recording.

The problem of recording high speed radio telegraph signals has been repeatedly attacked, using photographic tape records with the Einthoyen string galvanometer and crystal rectifier detector. The multiplicity of delicate adjustments, and the obliterations which even moderate atmospheric disturbances cause in the records, convince, in time, the most optimistic investigators in this field of the basic fallacy of this method.

Attempts have been made to record radio signals by means of the Telegraphone, but the fact that excessively loud signals (such as can be heard three feet from the telephone receiver) are needed to make satisfactory Telegraphone records, has kept this method inapplicable.

Now, however, with the three-step Audion amplifier relaying the detector signals, the Telegraphone becomes a simple and surprisingly reliable rapid recorder. A tape-actuated Wheatstone transmitter, controlling by two successive relays the wave length of a 12 K. W. Poulsen arc transmitter, sends Morse signals at the rate of sixty words per minute. The received Tikker signals are amplified and recorded on a Telegraphone wire running at a rate of about eight hundred feet per minute. In reproducing the record this wire speed is reduced to approximately one-third. The pitch of the tikker signals as thus reproduced is of course very low; but with the above speed-reduction ratio these signals, even without re-amplification, are still sufficiently loud to permit the use of a typewriter by the transcribing operator.

For speeds higher than sixty words per minute it is necessary to obtain the incoming signal in the form of a high-pitched note, which, upon reduction for transcribing at 25 words per minute, has still a pitch of some 150 cycles per second. Methods for accomplishing this latter have been recently worked out by the writer.

The Telegraphone rapid receiver has been in daily commercial use for several months at the arc stations of the Federal Telegraph Company, between San Francisco and Los Angeles. The method is not limited to arc transmitters. In fact, the musical spark stations offer certain advantages for this method of high speed recording. It is necessary only that the received signals should be 50 to 100 times "audibility" before amplification.*

While it is yet too early to speak authoritatively on the subject there appears no reason why the Audion amplifier should not also be applied with excellent advantage to submarine cable recording and relaying.

* Loud enough to be taken down by the operator, using the typewriter.

SYNOPSIS. *The improved Audion, containing one hot and two independent cold electrodes, is described, and its action as a sensitive detector in radio telegraph and telephone work outlined. Its action is shown to be not that of a simple rectifier or valve, but that of a true relay device. The secondary circuit of a radio receiving transformer is connected in shunt between the "grid" electrode and the filament. The telephone receiver and dry battery are connected between the plate electrode and filament.*

*There appears to be no known limit of sensitiveness below which the effect of minute received energy fails to be registered.*

*The device is constant and reliable, requiring only initial adjustments of battery voltages. The Audion is incontestably a "potential operated" device.*

*The normal current across the gas is of the order of a milliampere. Positive or negative charges impressed upon the grid causes a diminution in this current. Some unique unstable conditions, e. g. whistling are described.*

*The Audion is especially well adapted as a radio telephone receiver, and with or without the addition of the amplifier greatly increases the range of such communication.*

*The Audion as an amplifier of minute telephonic and other currents is described, together with circuits which permit successive amplifications, up to 120 times the initial energy.*

*This new amplifier, or relay, while exceedingly sensitive is not microphonic, nor delicate, but reliable and free from distortion. It promises a solution to the long-sought telephone-relay problem, and opens up new possibilities in micro-electrics. A sensitive and reliable calling device for radio purposes is readily attained.*

*The general use of magnetic telephone transmitters in place of microphones, together with smaller telephone cables, is suggested as a possible future development in telephoning.*

*In connection with the Telegraphone the new amplifier permits voice and music records, of practically any length, to be heard thruout large-sized rooms. Recording of rapid radio signals by means of the Telegraphone is now feasible.*

*The Audion amplifier may be applied equally well to problems of cable receiving and relaying.*

## DISCUSSION.

A partial reprint of Dr. de Forest's paper on "The Audion—Detector and Amplifier" appeared in "The Electrician" of November 21, 1913, page 285.

Professor J. A. Fleming objected strongly to Dr. de Forest's claims of priority in the discovery of ionised gas detectors of the Audion type, and embodied his objections in a letter addressed to the Secretary of The Institute of Radio Engineers. This letter was also printed in full in "The Electrician" of December 5, 1913, page 377.

Dr. de Forest, in an answering letter, upheld his original contentions, maintaining that there was an essential difference between the Audion and those forms of gas detector with which Professor Fleming had been engaged. Dr. de Forest's letter appeared in "The Electrician" for January 23, 1914, page 659.

In further support of his original contentions, Professor Fleming addressed a letter to "The Electrician," holding that his priority of invention in the ionised gas detector was established. This letter appeared on January 23, 1914, page 660.

In the "Elektrotechnische Zeitschrift" for November 27, 1913, page 1359, Eugen Reisz described a form of gas valve detector, and amplifier, in an article entitled "Verstärkung Elektrische Ströme, usw." The detector described therein is the gas valve which is claimed for Messrs. R. von Lieben and Reisz. The English description of the same device appears in "The Electrician" for February 6, 1914, page 726, et seq. In answer to the contentions of the authors of the above article, Dr. de Forest in an open letter in "The Electrician" for March 13, 1914, page 956, denies that their device is anything more than the Audion as discovered and worked out by him.

The above correspondence, being lengthy, is not here reprinted; and the reader is referred to "The Electrician" and the other periodicals mentioned for further details thereof.—EDITOR'S NOTE.

**John Stone Stone:** The problem of the telephone amplifier is one of great difficulty. I became interested in it in 1892, and soon found that the question of amplifying without producing distortion was prominent. The amplifying relays which were furnished were all mechanical instruments; their parts had inertia and consequently distortion was always produced. We never had

the instrument of our ambitions which, being without inertia, would amplify correctly even the weakest impulses without distortion. It is therefore with earnest scientific pleasure that I recognise that we have at last an instrument which uses the cathode stream to produce amplification, and which will therefore amplify even the weakest currents.

There is an application of this amplifier which is of great interest to me, namely to the field of "wired wireless." By this method of transmission it is possible to send simultaneously over the same line a great number of conversations, each being carried by its own extremely rapidly alternating current. The receiving station can be appropriately tuned to any of the frequencies used. This is an older art than radio telegraphy.. Up to the present it has not materialized because the energy of the currents thus transmitted was too small to enable competition with ordinary telephony. This new amplifier promises to bring the "wired wireless" telephone to a par with the usual wired telephone. There is then a prospect of a satisfactory solution of the problem of multiple telephony. As many as twenty messages might be transmitted simultaneously over the same line.

If any of the usual detectors in radio communication, e.g. the crystal rectifier, be overloaded, it is difficult to restore it to an adjustment for sensitiveness. Tinkering is required. Not so with the Audion. With excessive strength of signals, we get the blue arc in the bulb. It is merely necessary to open the battery circuit for an instant, to restore the Audion to full sensitiveness. There is no need to hunt for a sensitive point on a crystal. And the Audion is unique among detectors in that it is an amplifier as well.

**An Auditor:** Does the blue coating which forms on the plate render the Audion less efficient?

**Dr. de Forest:** If the bulb were run long enough this effect might lower the sensitiveness. However, the life of the bulb is three or four hundred hours, and in that time no lowering of the sensitiveness for this reason can be noticed.

**C. H. Sphar:** Is the "singing" of the Audion, when on critical adjustment, accounted for in the same way as the whistling on a telephone line when the receiver is held to the transmitter?

**Dr. de Forest:** Yes; it is due to an electromagnetic reaction in the Audion. A similar effect is produced in the telephone repeater. Probably in the case of the Audion it is due to an interaction of the charges on the grid and the wing.

**Chas. A. Le Quesne, Jr.:** I have noticed a ringing sound when the Audion is mechanically disturbed, for example, by jarring the table. What is the cause of this?

**Dr. de Forest:** It is due to the swinging or vibration of the grid. It is purely mechanical, and has never troubled us in our work.

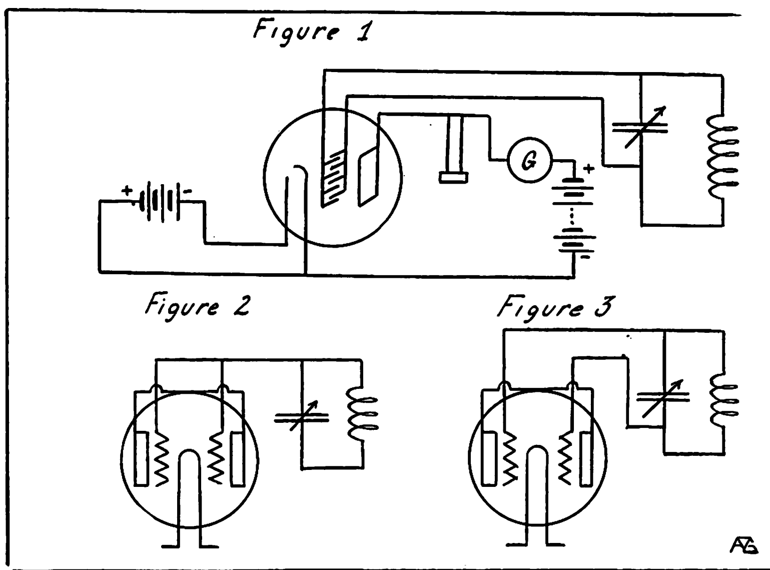
**An Auditor:** Why does the filament lean toward the grid when it has been in use for some time?

**Dr. de Forest:** If the Audion is properly suspended, in an inverted position, this does not happen. There might be a slight electric attraction between the filament and the plate, but I do not think its effect would be easily observable.

**Roy W. Weagant:** Is there any multiplication of the frequency of audible sounds by the Audion, as in an unpolarised telephone receiver?

**Dr. de Forest:** No such effect is found.

**Alfred N. Goldsmith:** In a recent modification of the Audion, due to Ma jorana, the plate and filament are connected as usual.




The grid, however, is double, consisting of two sets of interleaved but mutually insulated wires. Each of these sets of wires is connected to one side of the condenser in the radio receiving circuit. Majorana calls this grid an "electron deflector" or "deviator," and bases the action of this type of Audion on the deflection of the cath-

ode stream which occurs as the wire systems of the deflector are successively oppositely charged. The sensitiveness of this arrangement is given as superior to that of the usual Audion. May I ask if any experimental work has been done by Dr. de Forest with this arrangement? It is shown in Figure 1.

**Dr. de Forest:** I had previously tried the arrangement advocated by Majorana. Sometimes the sensitiveness is thereby increased, but with other bulbs it may be diminished. For example, using the latest type of Audion, with two plates and two grids, I have used the connections shown in Figures 2 and 3. The sensitiveness of the arrangement of Figure 2, which is high, is usually equal or superior to that shown in the Majorana arrangement.

**C. H. Sphar:** I have noticed an illustration showing the use of the Fleming valve in the secondary circuit of a step-up transformer, e. g. a ten inch coil. What is the purpose of that connection?

**Dr. de Forest:** I have never tried this. However, one can always wind the telephone receivers and the other portions of the radio receiving set to the suitable inductance and resistance so as to permit the proper functioning of the Audion without using such an arrangement.

**Charles A. Le Quesne, Jr.:** When one side of the receiving condenser is connected to the grid, and the other terminal of the condenser to one side of the filament, changing the latter connection to the other side of the filament alters the strength of the signals. Why?

**Dr. de Forest:** The antenna side of the receiving condenser should always go to the grid, and the earth side of the condenser to the filament of the Audion; so that the highest potentials possible are impressed on the grid.

**Lester Israel:** Dr. de Forest has mentioned the fact that, altho no sound is heard in the telephone when an Audion bulb is lighted, a distinct click occurs when it is extinguished. A very plausible explanation of this phenomenon occurs to me.

It is a well known fact that the emission of ions from a hot electrode practically begins at a red heat, and increases almost linearly with the temperature as a white heat is approached. From this fact it follows at once that current changes in the telephone circuit occur only when the temperature of the tantalum

filament is varying between red and white heats, and further that the current is very nearly directly proportional to the temperature above the red heat.

Now consider the manner in which the temperature of the filament changes between the above limits. When the lamp is lighted, the temperature increases very rapidly at first to above the red heat, and then more and more slowly, as the rate at which heat is dissipated approaches the rate at which heat is supplied. In consequence, the telephone current increases to its full value during a comparatively long period of time, probably between a tenth and fiftieth of a second.

When the lamp is extinguished, however, the temperature drop from white to red heat, and consequent current drop from maximum to a practical zero, occur very rapidly—probably in one one-hundredth to one five-hundredth of a second. This difference in the rate change of telephone current probably accounts for the phenomena mentioned by Dr. de Forest.

**Dr. de Forest:** This is probably the correct explanation.

**Charles A. Le Quesne, Jr.:** It has been mentioned that to avoid the blue arc on powerful signals a shunt resistance may be placed across the Audion. Must this shunt resistance have a high value?

**Dr. de Forest:** Of the order of magnitude of several megohms otherwise the sensitiveness of the Audion is diminished.

**G. H. Clark:** All other telephone amplifiers are of the carbon microphone type. Very slight mechanical disturbances interfere markedly with their action, and, tho I have investigated carbon amplifones, I have not found them to be successful, at least for weak signals. I have recently seen a carbon amplifier which does not "whisper," but it does not amplify sufficiently either.

In working with the Audion amplifier, I have found that the amplifications at the three steps (including all losses) were approximately 8, 64, and 200 times. I may also state that in working between Honolulu and Arlington, even when the signals were totally inaudible without the Audion amplifier, with it they could be heard very well.

**John L. Hogan, Jr.:** I wish to congratulate Dr. de Forest on this solution of the amplifier problem. In the 1906 paper, an arrangement was shown wherein a telephone in series with a galvanometer constituted the indicator. May I ask whether you have

determined why, altho changes in the intensity of the telephone signals sometimes occurred, the galvanometer deflections remained unchanged? It is my recollection that in 1906 you stated this was not understood.

**Dr. de Forest:** This may have been because the telephone was so much more sensitive than the galvanometer used. Since that time I have employed only the grid and wing type of Audion, but I have not investigated the matter further.

**John L. Hogan, Jr.:** From your experiments with the Audion, can you say that the modification in battery "B" current, due to impulses from incoming wave groups, is always in the nature of a pulsating reduction in amperage, a single pulse reduction being produced by each wave group? That is, does the "B" current value always have forced upon it a reduction corresponding (as plotted against time) to the boundary curve or "envelope" of each wave group? If this has not been proven, it seems possible that the peculiarly loud response of the telephones to impulses which would not deflect your galvanometer (as described in your 1906 paper) might be analogous to the action in tikker circuits. Where the rapid vibrating contact is used to discharge a resonating circuit condenser thru a telephone, the impulses applied to the latter are irregular in amplitude and polarity. The sum of all these discharges thru a definite time which is long compared to the time of discharge is nearly zero, hence a slow period instrument, such as a galvanometer, will show no deflection altho a telephone may be responding loudly to the individual discharge impulses. I have encountered similar effects when solid rectifiers were used, and so am suggesting the possibility of a like action in the case of the Audion.

**Dr. de Forest:** My understanding is that the Audion acts as you have first described, and therefore that the tikker is not analogous.

**John L. Hogan, Jr.:** When the Audion is operating as a detector, it is, then, a non-polarized device? That is, an incoming impulse will, regardless of its polarity, produce a proportional diminution in the battery "B" current?

**Dr. de Forest:** Yes. The reduction is produced sensibly without regard to the polarity of excitation.

**John L. Hogan, Jr.:** Is this effect or characteristic in any way altered when the Audion is operated as an amplifier?

**Dr. de Forest:** No, I believe not. I have found no reason to believe that change of excitation frequency produces any change in the method of operation.

**George H. Clark:** What relation is found between the sensitiveness of the Audion bulbs as detectors and their value for amplifier use?

**Dr. de Forest:** Good detectors are sometimes poor amplifiers, but the opposite relation is not found.

# RADIO RANGE VARIATION*

By Robert H. Marriott

*Past-President of the Institute*

Thruout this paper, whenever radio range variation is mentioned I shall refer to a variation in the distance over which messages could be transmitted and read on reception. This is a subject to which I have given considerable attention, having taken observations on it and on the strength of atmospheric disturbances intermittently over a period of about fourteen years. In the following paper I shall attempt to present a record of the most interesting and useful of these observations.

The first records which we shall consider were made at the Manhattan Beach station of the United Wireless Telegraph Company. This station was located at Coney Island in New York City, and its call letter was "DF" (American Morse code).

At the Manhattan Beach station care was taken to cut down all losses in transmission and reception. Air insulation was used wherever possible in the transmitting circuit, and wherever solid insulators were employed they were made as long and narrow as practicable. A United Wireless "Steamship Type" transmitter using about 2 kilowatts was installed in this station. The spark gap itself was not enclosed. For reception, inductively coupled tuners, equipped with Perikon detectors, were usually in use. The receiving apparatus was changed occasionally, but apparently the receivers used were so nearly equal in efficiency that no material change in the range of reception was thus produced.

The vessels worked with were mainly equipped with what were known at that time as the United Wireless 1 kilowatt sets. The evolution of this type of apparatus may be of interest. It was first known as American De Forest Wireless Telegraph Company equipment; later, with a few changes introduced, as United Wireless Telegraph Company equipment; and at present these sets, used at a looser coupling and frequently including non-synchronous rotary gaps, are known as American Marconi equipments. A

* Delivered before The Institute of Radio Engineers, January 7, 1914.

test on 28 of these sets showed transformer inputs between 350 and 1,850 watts, the average transformer input being about 1.1 kilowatts. The average antenna current on the ships at the time the tests shown on Chart 3 were made, was probably about 5 amperes. Characteristic wave lengths and couplings employed are indicated on Chart 4. The tuners used on board ship were equipped with carborundum detectors. They were, as a rule, inductively coupled.

Referring to Chart 3, Figure 1, there is shown the maximum daily range between 5 P.M. and 1 A.M. for the period between October 12, 1908, and October 15, 1909. The ranges, indicated by dots and connected by lines, refer to the *longest distances* over which messages were sent and received on the respective days. The distances were checked by reference to the message records kept on board the ship. Practically no records of distance were made except where the distance in question was actually attained in handling *business* either sent or received, *and acknowledged.* Messages handled during this time included approximately 115,600 words, of which about 82,800 were received and about 32,800 were transmitted, not counting checks, repetition, acknowledgements or conversation. The operators who made these records were selected for their reliability and were given a *bonus*, the amount of which depended on the *number* of words handled and the *distance;* that is, ten words sent or received over a distance of 1,000 miles paid a considerably higher bonus than ten words sent or received over a distance of 100 miles. Attention is called to the fact that these ranges represent the *maximum* distance attained on their respective dates.

In Figure 2 of the same chart, a rough estimate of the relative strength of the "atmospherics" for the same dates and times of day as those represented by the readings of Figure 1 is presented. The dots were placed in accordance with the report of the operator, who noted the strength of the atmospherics as heavy, medium or light, or else in similar terms. With the exception of short periods, two operators made these records, as is indicated in Figures 1 and 2. These operators did not express themselves in quite the same way in classifying atmospheric disturbances as to strength and quality.

A number of figures which follow are provided for purposes of comparison. Thus, Figure 3 shows the daily minimum, mean, and maximum Fahrenheit temperature, as reported by the Weather Bureau from New York City.

In Figure 4 are given the weekly averages of the daily maximum

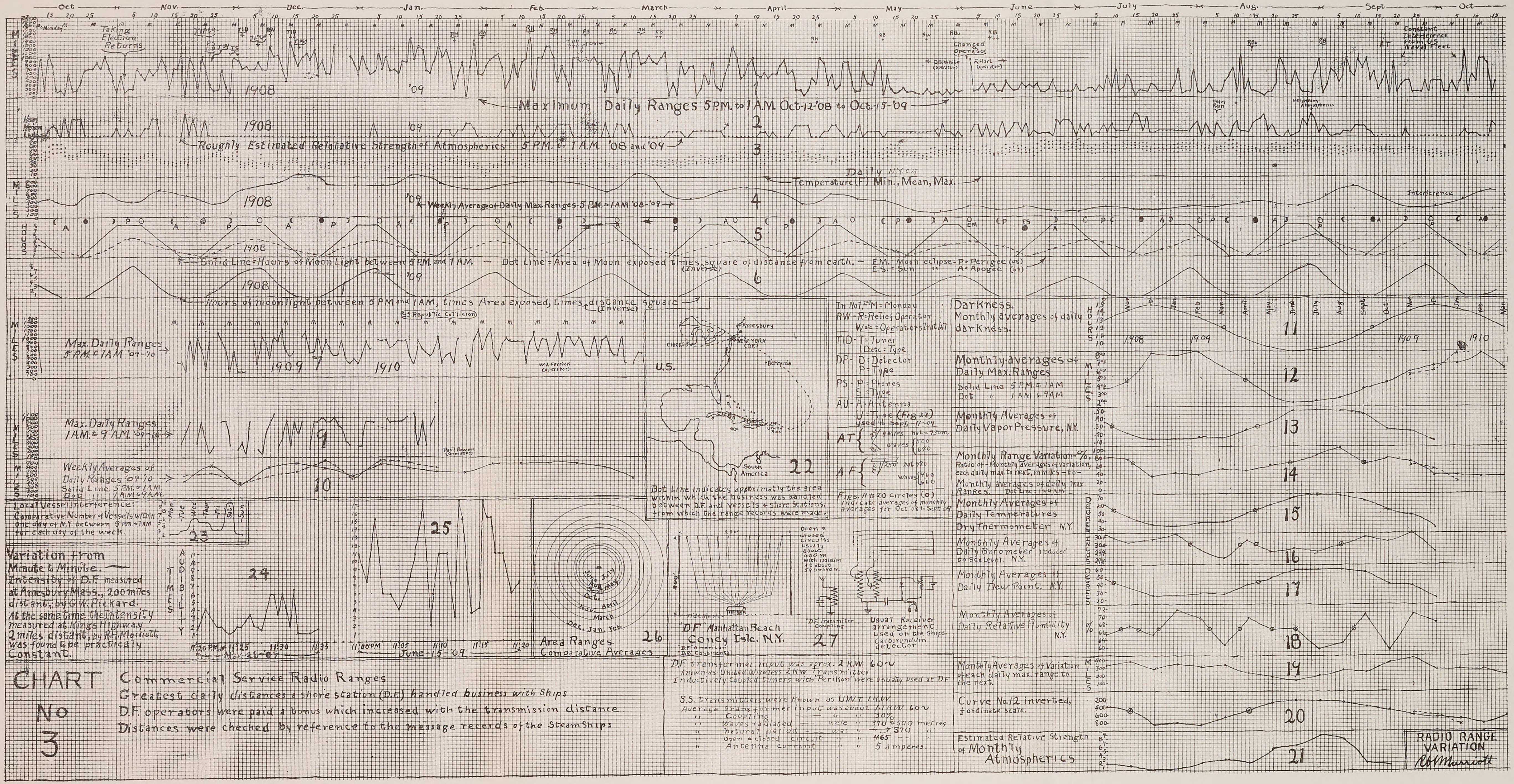



CHART No 3

Commercial Service Radio Ranges

Greatest daily distances a shore station (D.F.) handled business with Ships

D.F. operators were paid a bonus which increased with the transmission distance.

Distances were checked by reference to the message records of the Steam Ships

D.F. transformer input was aprox. 2 K.W. 60~

S.S. transmitters were known as U.W.T. 1 K.W.

ranges. These were obtained by taking the weekly averages of the ranges shown in Figure 1.

Figure 5 shows in the heavy solid line the number of hours of moonlight between 5 P.M. and 1 A.M. for the period of time covered by Figure 1; and the dotted line shows approximately the area of the moon exposed multiplied by the inverse square of the distance of the moon from the earth.

In Figure 6 is given a curve which represents the total moonlight between 5 P.M. and 1 A.M. It is based on the number of hours of moonlight during that time multiplied by the exposed area of the moon and by the inverse square of the distance of the moon from the earth. On comparing Figure 6 with Figure 4, it will be found that in some cases the curve of Figure 4 is low where the curve of Figure 6 is high, and conversely. That is, the range was greater when there was minimum moonlight and less when there was maximum moonlight. However, this might have been due to other things than the effect of the moonlight. For example, between September 21 and October 5, 1909, there is a decided dip in the weekly range curve corresponding to the peak in the total moonlight curve, but this dip in the weekly range curve was probably principally due to interference from the fleet of the United States navy, which was in the vicinity at that time.

Figure 7 is a continuation of Figure 1 for 1909 and 1910, and was obtained in the same way as Figure 1.

Figure 9 was obtained in the same way as Figure 1, except that it applies to the hours between 1 A.M. and 9 A.M. During this part of the day there were probably less interference and better atmospheric conditions, but there were not so many ships with which to work, because many of the operators were alseep during these hours. Vessels, as a rule, carried only one operator.

In Figure 10, the solid line shown is a continuation of the weekly average curve in Figure 4. The dotted line is a similar average curve for the hours between 1 A.M. and 9 A.M.

In figures 1 to 10, all dates mentioned refer to those given at the top of the Chart. The dates given for operation between 5 P.M. and 1 A.M. are always for the day preceding dates referring to operation between 1 A.M. and 9 A.M.

Figure 11 represents the hours of darkness by monthly averages from October 15, 1908, to March 15, 1910.

Figure 12 shows the range variation by monthly averages from October 15, 1908, to March 15, 1910. These quantities are the monthly averages of the daily ranges given in Figure 1. On comparing Figure 12 with Figure 11, it will be seen that the in-

crease in range is not as rapid as the increase in number of hours of darkness, and that the decrease in range is not as rapid as the decrease in hours of darkness. That is, the range curve may be said to lag behind the darkness curve, which probably would not have been the case if the ionization and consequent conductivity produced by sunlight were the only factors which determined the radio range.

In Figure 13 are shown the monthly averages of the daily vapor pressure at New York. It will be seen that this figure is something like an inverted range curve. There is a somewhat similar type of lag between the vapor pressure curve and the hours of darkness curve as mentioned in the preceding paragraph.

In Figure 14, the monthly range variation in per cent. is shown; that is, the ratio of the monthly average of the variation (of each daily maximum to the next daily maximum) to monthly averages of daily maximum ranges. This curve indicates that there really were more *so-called "freaks"* in the month of August than in the winter months; that is, the ranges showed a greater percentage variation in the summer than in the winter, altho the winter is usually spoken of as the period of "freak" work. Probably none of the variations mentioned should be called "freaks," since approximately similar variations occur on the average from year to year at the same season. They are simply the more pronounced examples of radio range variation.

Figure 15 shows the monthly averages of the mean daily temperatures in New York. It will be seen that this curve is also somewhat similar to an inverted range curve.

The monthly averages of daily dew point for New York are given in Figure 17. These also somewhat resemble an inverted range curve.

In Figure 18, the monthly averages of daily relative humidity are shown. As will be seen, the relative humidity during January, 1909, was high while the temperature was low. This may have something to do with the dip or minimum in the range curve for January, 1909. Moisture may have been deposited on the insulators to a sufficient extent to cause serious losses at both the transmitting and receiving stations.

Figure 19 gives the monthly average of variation in miles between each daily maximum range and the next daily maximum range. This variation is greater, so far as number of miles is concerned, in the winter time than in the summer time, altho it is smaller in percentage, as will be seen from Figure 14.

In Figure 20, an inverted range curve, with halved ordinates, is given for comparison with the other curves.

Figure 21 shows roughly the estimated relative strengths of atmospherics by monthly averages.

In Figure 22, the dotted line shows approximately the area in which the vessels working with Manhattan Beach were located, these being the ones with which the range records were made. Nearly all of the records were made from distances reached with ships. During the winter months, messages were exchanged with Chicago and vessels on the Great Lakes. On one occasion, Chicago was unable to hear a message sent from a vessel on the Great Lakes, but this message was copied at Manhattan Beach and re-transmitted by radio direct to Chicago.

In Figure 23, the curve ordinates are proportional to the number of vessels within one day's sail of New York, between 5 P.M. and 1 A.M., for each day of the week. It will be seen that the greatest number of vessels were within one day o' New York on Saturday, and that those vessels apparently caused sufficient interference to reduce the working range on Saturday during the winter months. This is evident by comparison with Figures 1, 7 and 9, wherein the "M" indicates each Monday of the week in these figures.

The intensity of the signals from Manhattan Beach received at Amesbury, Massachusetts, which is about 200 miles from Manhattan Beach (300 kilometers), is given in Figure 24. The intensity of these signals is expressed in number of times audibility, as measured by Mr. G. W. Pickard, using the shunted telephone method. At the same time, I measured the strength of the Manhattan Beach signals, using a small antenna at my residence about two miles distant from the station. There I found the signals to be about 30 times audibility, using the same method, and I found practically no variation in the strength of these signals. The same applies to Figure 25.

Figure 26 shows the comparative areas over which communication could be maintained at different times of the year, and is based on the monthly averages given in Figure 12, used as radii.

A diagramatic sketch of the arrangement at the Manhattan Beach station, and the methods used for coupling the open and closed circuits at this station and on the ship stations are given in Figure 27.

We pass to Chart 1. In the upper part, A, of this chart, there is shown, in solid lines, the vapor pressure at 6 P.M. at Denver, Colorado, for 1906, the vapor pressure at 6 A.M. being shown in

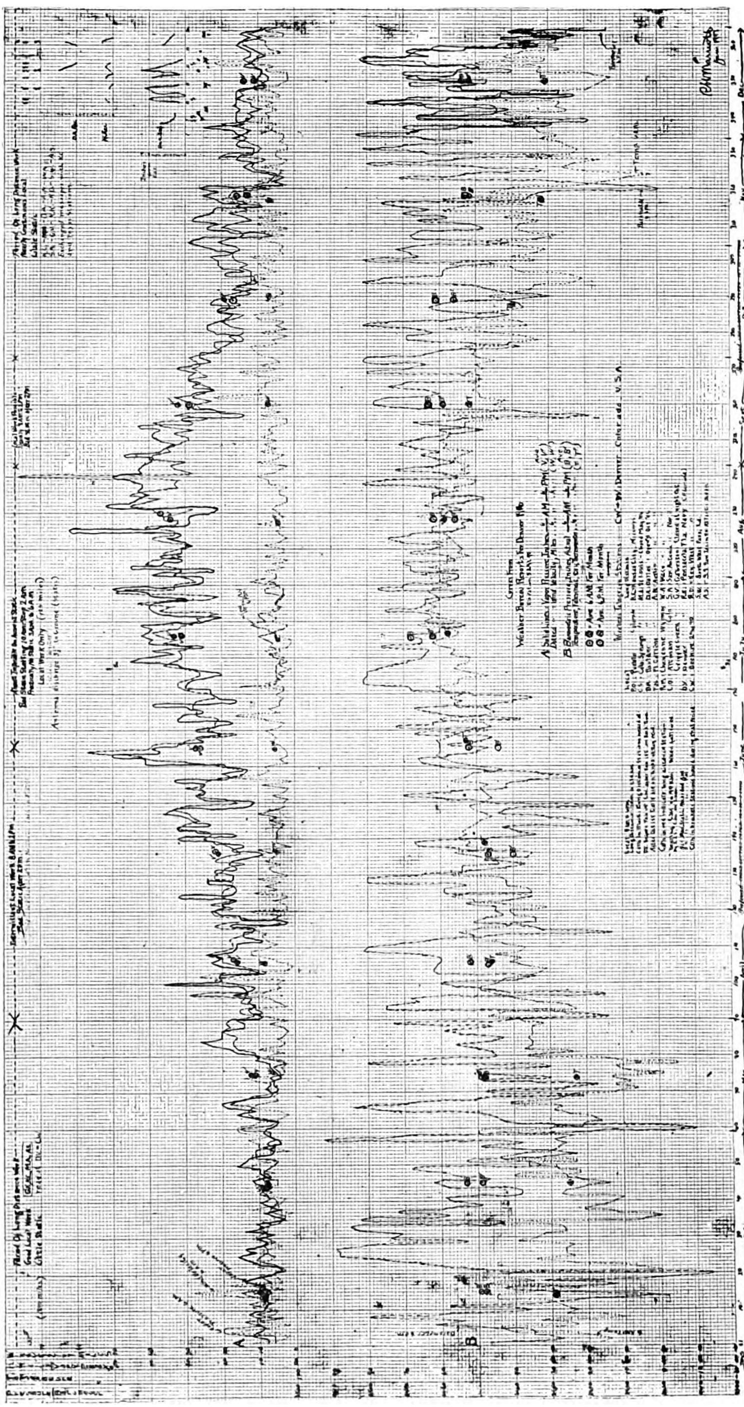



CHART 1.

light lines with superimposed dashes. The wind velocity is shown by the dotted line. The lower part of the chart, B, shows barometric pressure and temperature. In Colorado, the period between about October 1st and April 1st was the period of minimum atmospherics, of excellent local communication, and of frequent long-distance work. January was probably the best month for long distance ranges. Between about April 1st and June 15th local work with Cheyenne (Wyoming), Fort Collins, Boulder, Colorado Springs, and Pueblo (Colorado) was intermittent in character. Atmospherics usually became stronger at about 2 P.M. During the month of September some similar effects were observed. From about the middle of June to the 1st of September it was frequently almost impossible to carry on even local work because of the heavy atmospherics. During this period these disturbances began about 10 A.M. and lasted until about 2 A.M. Between 2 A.M. and 10 A.M. there was frequently only comparatively slight disturbance from atmospherics. During this period of the day time, for example when there was a storm near Pike's Peak, long spark discharges could be obtained between the antenna and ground. From an antenna 200 feet (60 meters) high at Pueblo, on one occasion I obtained an intermittent discharge about 3.5 inches (9 cm.) long. The frequency of this discharge increased as the spark gap shortened, until finally a short hissing spark was obtained.

Figure 35 of Chart 2 is intended to point out the periods of good and poor reception at Denver. The Denver antenna was similar to that at Manhattan Beach, but the ground was very dry. The receivers were like those used for ship work. On the dates for which no records are shown on Figure 35, no receiving was done at the Denver station. During this time Kansas City sent nightly in order that we might be able to carry on these tests. The records from other stations were naturally based on business handled by these stations under ordinary conditions, and I do not know whether they were operating every night during the time I was receiving at Denver.

In Figure 36 are given the strength of the signals received at Denver in number of times audibility. The signals from Kansas City were measured by the distance the telephone could be held from the ear and the signals still read; and this method was later compared with the shunted telephone method and is here indicated in times audibility by the shunt method. Kansas City did no transmitting after about January 15, 1907.

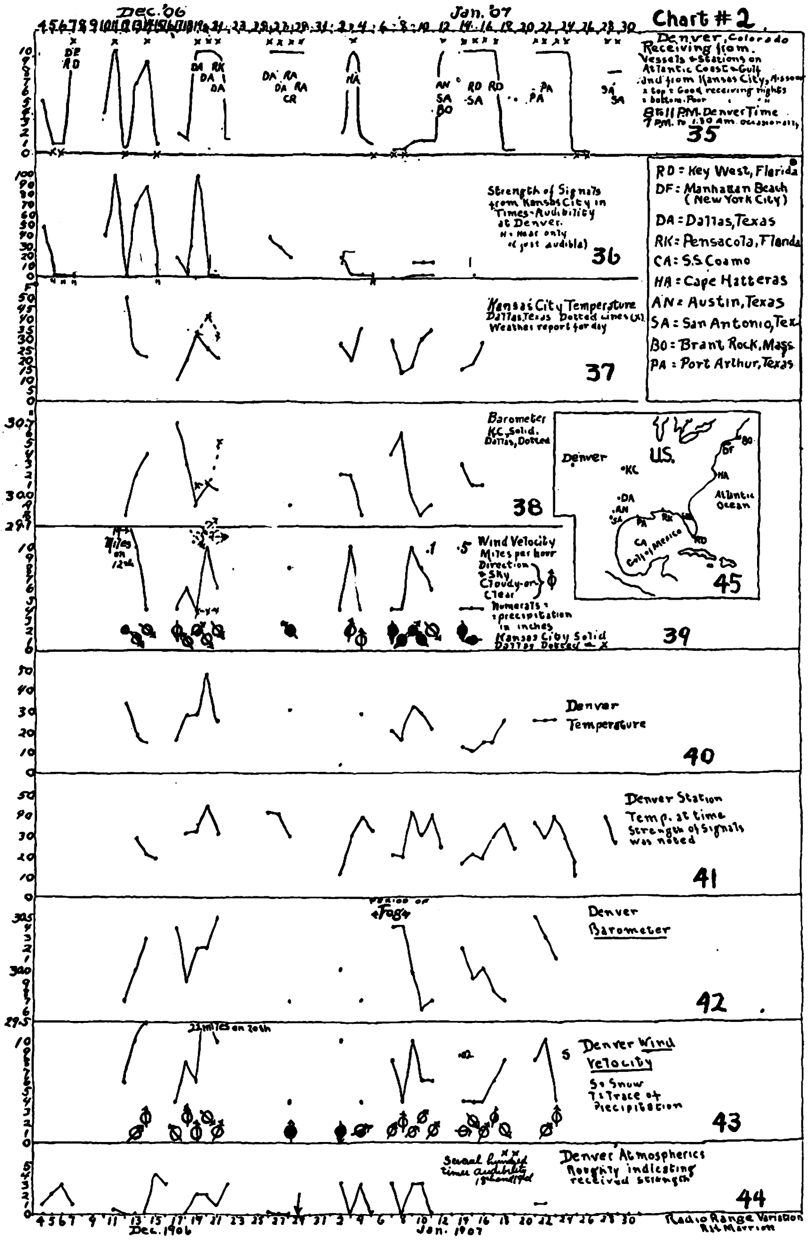


Chart # 2
Denver, Colorado Receiving from Vessels & Stations on Atlantic Coast & Gulf and from Kansas City, Missouri
Dec. '06
Jan. '07
Strength of Signals from Kansas City in Times-Audibility at Denver.
Kansas City Temperature
Barometer
Wind Velocity
Denver Temperature
Denver Barometer
Denver Wind Velocity
Denver Atmospherics
RD = Key West, Florida
DF = Manhattan Beach (New York City)
DA = Dallas, Texas
RK = Pensacola, Florida
CA = S.S. Coamo
HA = Cape Hatteras
AN = Austin, Texas
SA = San Antonio, Texas
BO = Brant Rock, Mass.
PA = Port Arthur, Texas
Radio Range Variation


CHART 2.

The strength of atmospheric disturbances during the time of the measurements is roughly illustrated in Figure 44.

Figure 45 shows the relative positions and distances of the stations heard at Denver during December and January, 1906 and 1907.

The remaining figures on Chart 2 indicate the weather conditions at Kansas City and Denver during this period, as reported by the Weather Bureau.

Returning to the work of Manhattan Beach, Chart 4 shows a fairly characteristic list of the wave lengths and other data for the vessels which did the work given in Figure 1 of Chart 3. Data on some vessels with which Manhattan Beach did not work at that time, is recorded on Chart 4, and, on the other hand, some vessels with which Manhattan Beach did work during that period are not shown on Chart 4.

It is of considerable interest to note that out of twelve cases in which vessels worked over 1,000 miles with Manhattan Beach, it was found that in 10 cases the free end of the antenna was pointing toward Manhattan Beach and in 2 cases the free end was pointing away from it.

The effect of outside noises on the range of reception was shown quite markedly by the following. When measuring the strength of incoming signals by the shunt method, signals which were 20 times audibility at quiet moments, were reduced to 7 times audibility when a train passed the receiving station.

The Manhattan Beach station was so located that the tide rose and fell directly under the station and this alteration in the ground conditions may have somewhat affected the range.

Variations of range from minute to minute are sometimes caused by heating of the spark gap, and very marked variations in antenna current have been observed when quenching gaps were used without a fan or blower to carry away the heat produced. A somewhat similar variation was sometimes noticed using the plain United Wireless gaps on the ship stations.

The greatest number of long distance records made by a ship between October, 1908, and October, 1909, were achieved by an operator on a very small vessel, ship Number 53, shown on Chart 4. This vessel was only about 300 feet (90 meters) long, and was of about 1,900 net tons displacement. The long ranges achieved were apparently very largely due to the excellence of the operator in matters of skill, judgment, and perseverance.

Before I started the operating scheme with bonus for these

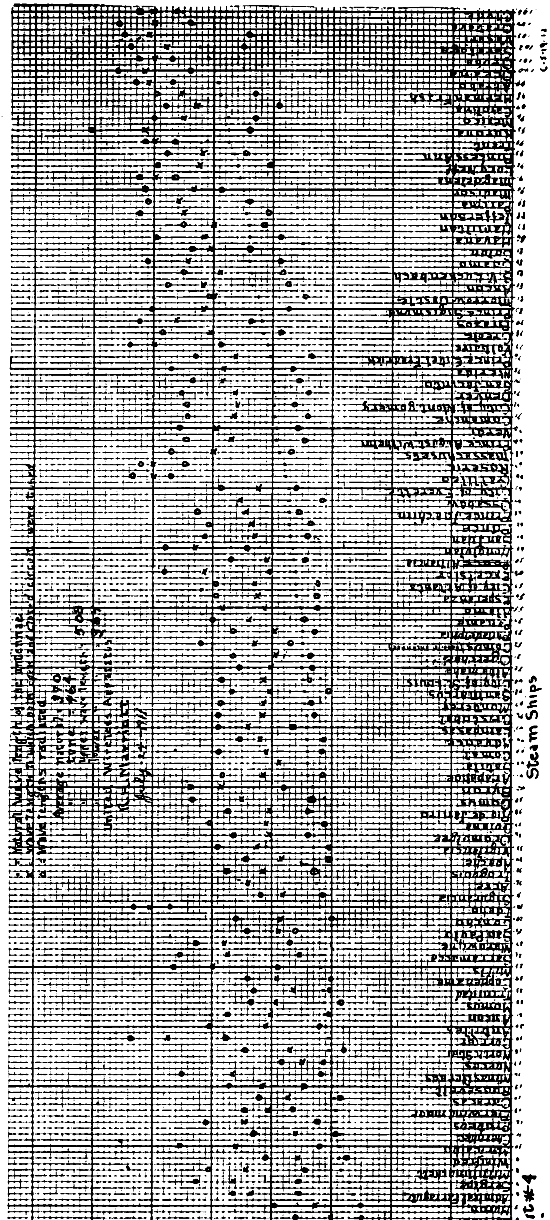



CHART 4.

tests at Manhattan Beach, the operators for that station were not particularly carefully chosen, and they were given no particular incentive to handle considerable amounts of business, except that they were reprimanded from time to time if they did not carry on sufficient work. As a matter of fact, they handled very little business. When selected operators were in charge and were paid a bonus depending on the amount of business handled and the distance over which this business was handled, the range was materially increased and the business handled was multiplied many times. In one instance the increase over a corresponding time was found to be 2,700 per cent.

Apparently, in the winter time, the operator expects to receive long distance messages, and he therefore makes a greater effort to carry on such work, but during the time of summer atmospheric disturbances he is discouraged by the difficulty of communicating over long distances and therefore he does not even attempt long distance work. There are apparently considerable individual differences in the ability of persons to receive signals, and the acuteness of the individual in receiving signals also varies from time to time and from place to place. For example, among other peculiarities, it was noted that weaker signals could be received in a room which was noticeably cold than when the room was quite warm. It was also noted that if barely audible signals were received, placing a cigar in the mouth rendered the signals inaudible. It is quite clear that a great amount of the variation in the strength of received signals which has been ascribed to ionization and consequent conductivity of the atmosphere is due to some other factors.

Some interesting matters are illustrated in Figures 12 and 15 of Chart 3. Considering monthly averages, and in some cases daily and hourly values of the strength of received signals, it was found that the range increased as the temperature decreased, even under unfavorable seasonal conditions. Perhaps sufficiently careful measurements of temperature of several points between the stations under consideration would show temperature changes corresponding to the minute to minute radio range changes.

While the daily local temperature may not be an accurate indication of the average temperature over the entire range of communication, the monthly average local temperature is probably proportional to the monthly average temperature over the range between stations. Figures 1 and 3 of Chart 3 show that the local daily temperature is not closely related to the daily range variation. It was also found that cloudy conditions in the

neighborhood of Kansas City frequently resulted in weaker signals as received in Denver. Referring to Figures 35 and 36 of Chart 2, it will be seen that Manhattan Beach, New York, and Key West, Florida, were heard at times in Denver, altho the signals from Kansas City were weak. According to the weather maps for that date, cloudless weather was practically universal for the section of the United States east of Denver, but a rapid change of temperature was occurring in the vicinity of Kansas City. On December 19th, signals from Dallas, Texas, and Kansas City were strong while other stations were not heard at all. From the weather maps for that date, it was seen that there was a cloudless area from Denver to Kansas City and Dallas, with a cloudy and rainy area east of Kansas City and Dallas. On December 21, 1906, Pensacola, Florida, and Dallas were heard loudly at Denver, while Kansas City was weak. At this time there was a cloudless space which included Denver, Dallas, and Pensacola, and there was a large equal pressure area surrounding Denver. On January 3, 1907, Cape Hatteras and Kansas City were loudly received at Denver, altho it was cloudy with precipitation over the greater portion of the area between Kansas City and Cape Hatteras. From December 7th to January 3rd there was a high pressure area in Colorado, southwest of Denver. On January 12, 1907, Austin, Texas, San Antonio, Texas, and Brant Rock, Massachusetts, gave signals which were strong in Denver, and yet the Kansas City signals were weak. At that time Austin, San Antonio, and Denver were in a cloudless area, while it was cloudy near Kansas City and somewhat cloudy with precipitation between Denver and Brant Rock, Massachusetts.

It is a question for careful consideration whether the strength of received signals may be influenced more by the refracting, reflecting or absorbing powers of the atmosphere at or near the receiving station than by the same atmospheric conditions at or near the transmitting station. It may be reasonable to expect that the former is the case.

High relative humidity, or rising temperature with less relative humidity on cloudy days, have repeatedly been found to produce very marked leakage of transmitter current by decreasing insulation. Extreme cases of this effect have been observed during January and frequently in the summer months. Damp spark mufflers caused considerable leakage losses in the United Wireless ship transmitters. In general, it appears that water in the air seems to be markedly associated with range variation. Such moisture directly decreases the range when it condenses on the surfaces

of the transmitter and receiver insulators. In cases where the transmitter spark gap is placed directly in the antenna circuit, moisture frequently causes the radiation to drop to zero. When coupled circuits are employed, moisture frequently lowers the current in both the open and closed circuits, the diminution of current in the open circuit being sometimes as much as 25 per cent. Marked losses at the receiving station have also been noted. In some cases, these were apparently due to moisture on crystal detectors, and the operation of such detectors was improved when the temperature was raised above that of the surrounding air.

Water vapor in the air seems to be intimately connected with atmospheric disturbances, both when these are produced by direct contact of the antenna with charged particles and also when the disturbances are produced by distant electrical discharges. Water vapor in the air possibly has a greater reflecting, refracting, and absorbing effect in transmission than is commonly attributed to it. Particularly is this the case if the density of the vapor is markedly non-uniform. If water is condensed on the surface of intervening vertical obstacles of large dimensions, it may also cause a material loss of energy from the wave.

Atmospheric disturbances in general may be said to cause more serious and erratic changes in the range of transmission than is commonly believed. Measured in arbitrary units, the atmospherics in Colorado, (expressed in terms of "times audibility") were roughly proportional to the fifth power of the vapor pressure, provided the vapor pressure were replaced by ten times its actual value; that is, the fifth power of ten times the vapor pressure approximately equaled the sound produced by atmospherics expressed in "times audibility." For example, from section A of Chart 1, the average 6 P.M. August vapor pressure approximately equalled 0.37 inches, (0.94 cm.). If ten times 0.37, or 3.7, be raised to the fifth power, the result is 663. That is to say, atmospheric disturbances approximate 663 times audibility in August. In January and February, they averaged between one and two times audibility.

As will be noted in Figure 44 of Chart 2, they were very strong on January 18th and 19th. On December 29, 1906, the atmospheric disturbances were possibly fifty times audibility at 8 P.M. and decreased very rapidly in strength as the evening advanced. This decrease with increasing darkness was characteristic for that season but was particularly marked on the date mentioned.

Possibly a greater decrease in range is sometimes caused by

atmospherics than can be accounted for by the strength of the sound due to them in the telephone receivers. Such atmospheric disturbances may markedly decrease the sensitiveness of the detector. Furthermore, closing a spark gap in the antenna circuit has been found to increase materially the spark frequency during times of heavy static. The sounds produced when receiver circuits are rapidly opened and closed during periods of practically inaudible atmospherics, as well as other observations, lead me to believe that under some conditions there may be atmospheric discharges which follow each other at a rate above audibility, and that these, altho they are not heard, decrease the sensitiveness of the detector for signals.

As a plausible explanation of some of these effects, we may consider that during times of high vapor pressure there are more particles of water carrying electric charges present in the air; and these may be discharged by contact with the antenna. Then again, they may combine to form larger aggregates of water which discharge to other conducting bodies, such as other bodies of water or the earth. There are thus produced electromagnetic waves, which are picked up by the receiving antenna.

If we assume that the air contains one charged particle per cubic foot, such charged particle being just capable of producing an audible disturbance, and that the antenna presents a contact area of about 20 sq. feet to the air, then if the air be moving against this surface at the rate of 1.5 feet per second, or about 1 mile per hour, there will be about 30 discharges to the antenna per second. If this air have a velocity of ten miles per hour, there would be produced 300 discharges in the antenna per second; and so on. If, however, there are a thousand charged particles per cubic foot of air instead of only one, then an air velocity of one mile per hour would correspond to a discharge rate of 30,000 per second, which is practically an inaudible frequency. Even tho the particles in question are not uniformly distributed, provided the discharge rate is very high, the detector might be rendered in effect insensitive to incoming signals, altho the sound due to atmospherics might be weak, especially if there were no very marked grouping of the charges. An effect of this type has seemed to occur on a number of occasions, particularly during dust storms in Colorado. Also, I have been lead to believe that this occurs at times of a redistribution of charged moisture near the antenna.

It has been reported that atmospheric disturbances nearly always follow a sudden change of wind on the north Atlantic coast, and that this is particularly the case when the wind changes from

south to north. It is further stated that atmospherics always accompany a rise of temperature in this region, and that they decrease when the temperature falls.

Perhaps it may be said that some of the requisites for great ranges are maximum darkness with continued, stable, uniform, and cloudless atmosphere at low temperatures and low vapor pressures between the transmitting and receiving stations, and that these conditions should obtain for considerable areas surrounding the stations and particularly near the receiving station. Conditions which approach the opposite to those mentioned will permit only very short ranges; and such conditions are maximum amount of daylight, unstable, stratified, clouded atmosphere at maximum temperature and vapor pressure between the stations and in the neighborhood of the stations, particularly in the neighborhood of the receiving stations.

A portion of the radio range variation may be due to ionization produced by the light from the sun. However, the heat which is received from the sun directly and stored by the earth may vaporize water and thus produce a portion of the radio range variation. Furthermore, the suspended water vapor may be the vehicle for the electric charges which so markedly affect radio service ranges.

It will be seen that since the heat absorption by the earth and the vaporization of the water lag somewhat behind the corresponding rising and setting of the sun, the range curve will naturally lag behind the darkness curve; and that the ionization produced by sunlight may cause the range curve to be sharper than the temperature curves. These points are well indicated in Figures 11, 12, 15 and 20 of Chart 3.

As shown by Curve 1 of Chart 3, the *best* night ranges obtainable were quite small, and occasionally fell to 100 miles (160 km.) and less during the summer months. The ordinary induction coil apparatus now supplied for final recourse in case of distress apparently has a very much shorter range. It gives only about one-third of the antenna current produced by the ship sets we have been considering, and the sound which it produces is harder to read thru atmospherics.

From reports which have been received, the service range from steamship radio equipments now in use, and similar to the United Wireless one-kilowatt transmitter, may be even less than at the time these Manhattan Beach tests were made. The reason for this is the greater interference which has resulted from placing practically all equipments on a wave length of 600 meters, whereas formerly the wave lengths of 105 vessels, as shown in

Chart 4, were between 230 meters and 700 meters, each vessel radiating two waves. Greater service ranges and more efficient service would probably be obtained if the vessels had had loosely coupled inductive sets, so that they would have radiated practically only a single wave at the wave length to which both the open and closed circuits were adjusted. In the case of these 105 vessels, the wave lengths would have been between 300 and 600 meters.

Commercial business and distress communication could probably be kept above a fairly satisfactory minimum of range and efficiency by using more modern and proven apparatus than is in use at present. For example, efficient quenched spark apparatus furnishing notes of an audio or sound frequency of from 800 to 1,200 cycles per second with an easily variable output of from 500 to 1,200 watts in the antenna would be far more satisfactory. The antenna output could be varied in accordance with the requirements imposed by atmospheric conditions. The highly sensitive crystal and gaseous detectors, supplied with ample spare parts, should be provided. However, a spark frequency which enables reading thru atmospherics should also be used. In addition, an emergency storage battery of sufficient capacity to supply full power to the transmitter for message service during six hours would be of great advantage. And further, the salaries paid to operators should be in keeping with their responsibility and should be made sufficiently high to raise radio operating to a profession worthy of consideration by experts. Such modern apparatus and better paid operators have been tried, and are in use on one line of steamships, and the results have been markedly successful. It seems that commercial radio practice is altogether too far behind the radio scientists and engineers. A greater amount of effort should be applied toward bringing into use highly efficient, powerful, and reliable apparatus, in the hands of properly paid expert operators.

It is quite clear that in order to study radio range variation and atmospherics, as thoro a record as possible of weather conditions around and between the stations should be obtained. The amateur is probably a particularly appropriate individual for the study of ranges and atmospherics, because his financial situation is not dependent upon the nature of his reports. It may well be that the studying of radio ranges and atmospherics will be of considerable use to weather bureaus. Possibly we shall obtain considerable information regarding the upper atmosphere thru such study, and this, too, of a nature which cannot be ob-

tained by present methods. In addition, such study may get us much data concerning the lower atmosphere, and thus assist and supplement our present methods. For the purposes of such measurement, the time signals which are sent out by such stations as Arlington may be received in various parts of the country and be carefully measured for intensity.

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## DISCUSSION.

**Vice-President John Stone Stone:** To The Institute of Radio Engineers I wish to state that I am honored by my election to the vice-presidency of that body.

Mr. Marriott's paper is rarely encyclopedic. Even the human element in its effects upon radio range variation has been considered. I think Mr. Marriott may have underestimated the influence on range variation of the diurnal variation; that is, the effect due to the sun's rays on the upper layers of the atmosphere. It may not seem to be very important, and yet it may prove the key to many of the effects observed. The losses which the sun's rays indirectly effect are due to currents which are conductively produced in the upper air layers by the traveling electric waves after the sun's rays have imparted conductivity to this portion of the atmosphere thru ionization. The currents thus produced vary directly as the conductivity, and they also vary directly as the potential gradient on the wave front. It may be that continuous waves are more effective because, for the same R. M. S. energy value, their wave front potential gradient is less than for strongly damped waves.

Recently some long-distance tests have been made, covering several thousand miles, and during these tests, the continuous and the damped waves were compared as to the absorption they experienced. The continuous waves proved to be much less affected by sunshine on the upper atmosphere. This immediately suggests how sunlight absorption can be successfully cut down.

**John L. Hogan, Jr.:** It has been suggested that atmospherics at a frequency above audibility may exist. In this connection the following observations are of interest. A continual succession of sparks may sometimes be drawn across a $\frac{1}{8}$-inch (3 mm.) gap from an open antenna. This is usually explained as due to a succession of charged dust or water particles coming into contact with the antenna. It is, in fact, sometimes possible to get 2- or

3-inch (5 to 8 cm.) sparks in this way. And yet, when the antenna is grounded thru an ordinary receiving set, no sound is heard in the telephones. This may be because there is a succession of small but very frequent charges passing down the antenna, or else that the individual charges passing down the antenna are too small to produce an audible effect. When the heterodyne receiver is used with an antenna under these conditions, sometimes a steady hiss is heard in the receivers, altho no sound could be heard with the usual receiving set with crystal detector. In this case the heterodyne oscillator is tuned to nearly the wave length of the antenna.

In connection with Dr. Austin's long distance tests comparing the arc and spark transmitters, and Mr. Stone's comment on them, it seems that the simple potential gradient explanation of absorption is new. We must, however, be careful not to confuse energy and power. The gradient may be much less on the front of the continuous wave, but the total time during which the absorption is taking place may be much greater.

**John Stone Stone:** In answer to Mr. Hogan's last remark, the volt-ampere curve for currents in ionized gases at low pressures indicates that absorption may be more marked in proportion at high potential gradients than at low, so that the effect of the greater time of absorption for continuous waves may be more than offset by the relatively great absorptive power of the gas at higher potential gradients.

The absorption due to conducting obstacles in the path of the waves will in general be small, unless resonance phenomena occur therein. But tho such resonant absorption will be greater for continuous waves than for damped waves, it will be of rare occurrence, while with damped waves, and particularly with highly damped waves, all conducting obstacles will respond to and absorb the energy of the waves.

**Dr. de Forest:** Remarkable distances are sometimes covered in the daytime using continuous waves. Thus, 12 kilowatts has been used for transmission over 1,000 miles (1600 km.) by daylight. Probably reflection in the upper layers of the atmosphere and diminished ground absorption account for this unusual range.

The superiority of the arc transmission over the spark transmission gave rise to a lively discussion in "The London Electrician." The foreign authorities hesitated to accept Dr. Austin's conclusions at first. Yet there was every reason to expect his results.

Tyndall showed the reflection of sound waves by rising or

vertical air sheets or strata of heated air, and the phenomenon has been reproduced in the laboratory. Similar reflecting layers exist for electromagnetic waves. Hence we obtain a less absorption by night than by day.

That these reflection effects are often extremely prominent is shown by the short wave to long wave reversal effect (PROCEEDINGS INSTITUTE RADIO ENGINEERS, Vol. I, Number 1, page 42). Using two waves of slightly different length, signals by one will rapidly become very loud and those by the other disappear (working with arc sets, of course). In fact, two stations near San Francisco, and six miles (10 km.) apart, showed the following peculiarity at times. One received the best on longer waves, and the other on the shorter waves; the common distant station sending continuous waves. This effect has never been observed from spark transmitters except possibly from the best quenched spark sets.

**John Stone Stone:** Has the tikker ever shown a continuous radio frequency static, and an inaudible static such as described by Mr. Hogan?

**Dr. de Forest:** Yes, signals just like those from the arc are thus received. This is caused either by continuous wave static or by a *very* rapid succession of damped wave trains. The tikker would hardly enable us to differentiate between the two cases. In this test, the tikker was inductively coupled to the antenna circuit.

**Austin Curtis:** On a ship's antenna, just before a thunder or snow storm, there can be produced a rapid succession of discharges. These are sometimes loud, and sometimes nearly inaudible. The effect is quite easily produced, even wind carrying moisture giving a swish as it blows across the antenna. If the ship rolls to windward, the strength of the discharge increases and its group frequency increases, and when the ship rolls to leeward, the strength of the discharge diminishes and the group frequency is lowered. This shows that particular sort of discharge here considered is caused by charged particles of air or water being driven against the antenna by the wind, the group frequency and also the intensity depending on the number of charged particles striking the antenna per second. The detector was inductively coupled thruout.

**Austin Curtis** (by letter): So far as the variation of range with temperature is concerned, I may say that in the tropics the changes caused by temperature alone are small. To begin with, there is

a rainy and a dry season, rather than a cold and a hot season. Best reception is accomplished in the dry hot season, which is when the sun and the equatorial rain belt are distant from the station, the sun is not directly overhead, and the static is not bad. As the sun gets nearer the station, it brings the rainy season with it, and the static becomes very bad, a continuous roar at night of about 500 times audibility being the rule. But signals are also much weaker in the morning, when there is little static, than in the dry season.

The variation in range between December and June is much less in the South Atlantic than here (at least, as far south as Buenos Ayres), but we find there irregular short freak periods, of two weeks or so at a stretch. The continuous roar of static which commences with sunset in the summer in the North Atlantic, and is very weak or absent in the winter, may be explained by the moving of the "equatorial calm belt," with its thousands of lightning storms, north and south with the sun. It is several hundred miles south of the equator in our midwinter, and several hundred miles north in our midsummer. The static coming from this source may be sharply separated from that caused by local thunder storms; the one being a dull, continuous roar, and coming only at night, the other a succession of sharp, distant discharges.

Static discharges in the tropics may thus be divided into distant and local static. The long distance static increases as the rain belt approaches the receiving station. (See also PROCEEDINGS OF INSTITUTE OF RADIO ENGINEERS, Vol. I, Number 3, pages 70 and 72.)

**Julius Weinberger:** F. Kiebitz in a recent article in the "Jahrbuch," * gives the results of calculations of the refractive index for electromagnetic waves of air containing various amounts of water vapor. The effect of the varying refractive index of the air at different heights is to cause the electric waves to be bent toward the earth (or rather the effect is to tend to make them follow the curvature of the earth) to a considerable extent. He also shows that, while this varying index of refraction will not entirely account for long distance transmission, it still has a decided influence. He further assigns to the presence of more water vapor over the ocean a portion of the well-known superiority of over-water transmission.

**Mr. A. E. Kennelly** (communicated): Mr. Marriott's paper is of great interest from many standpoints, but particularly on

* Jahrbuch der Drahtlosen Telegraphie, Vol. 7, page 154.

account of its wealth of statistical material. The relation between season of the year and the average range of signaling from "DF" is very marked, being apparently four times greater in midwinter than in midsummer, corresponding to a relative ocean-area range of sixteen to one under those conditions. The paper throws much light upon the climatic and atmospheric conditions attending this remarkable annual cycle of range variation.

Comparing Figures 11 and 12 on Chart 3, it might be supposed, at first glance, that from their close resemblance the range depended directly upon the daily darkness, as well as on the length of night time in the twenty-four hours. The daily range curve seems to lag about a month behind the daily darkness curve. This resembles the annual mean-temperature curve, which is shown in Figure 15 to lag behind the solar cycle by about the same amount. The question presents itself as to how far the seasonal variation in range is due to solar radiation acting directly on the atmosphere by ionization, and how far to secondary effects of that radiation, such as on water vapor in the air.

A satisfactory solution of this problem may take a long time to attain. It is possible that both direct and indirect actions of insulation are involved. That is, part of the diminution in summer range may be due to a more powerful ionization of the air during summer daylight hours, and part to the effects of more water vapor in the air during summer. It is to collections of observations such as are given in this paper that we must look for aid in arriving at a judgment.

The effect of aqueous vapor might manifest itself either at the sending and receiving aerials or in the atmosphere between them. Mr. Marriott points out that electrified water droplets, impinging on the receiving aerial, could account for at least a part of the disturbances. On the other hand, such observations as are indicated in Figures 24 and 25 of Chart 3, where rapid fluctuations appeared in received signals at 200 miles range, whereas no such fluctuations were found at 2 miles range, suggests that the disturbing influence was in the intervening 200 miles of air. One might suppose that intervening cloud-like masses of water vapor, undergoing change of state, such as evaporation or condensation, could account for the erratic changes shown.

Co-ordinated records on the part of amateur radio telegraph operators, at many different points of the country and at various hours of the day, employing an approved technique, might be able to throw much light on this mysterious and fascinating sub-

ject. It is to be hoped that the Institute of Radio Engineers will appoint an active committee for promulgating such activities.

**George H. Clark:** A very striking illustration of the effect of atmospheric conditions on radio ranges was observed several years ago during a long distance test between a high-power shore station and a ship. The curve of received signals was quite regular, until one afternoon when the distance between the stations was about 1,000 miles. The weather was very sultry and the humidity excessive at the time, and the signals measured only one-fourth the value that was to be expected from the extrapolated curve. After a time a lightning storm was seen approaching from the direction of the sending station, passed over the receiving station, and receded in the opposite direction. The air became cool and refreshing and the humidity decreased. The received signals showed a remarkable increase, the measured value being several times greater than would be expected from the curve. Both tests were made in daylight, and were about three hours apart. On the next day, when the weather conditions were "average," the signals fell to the value indicated by the curve.

**John L. Hogan, Jr.** (by letter): Referring again to the much discussed differences between arc and spark transmission absorption, I would say that while the suggestion that a reduced absorption might be due simply to a change in potential gradient seemed new and possibly not valid, the conception involving the resistance-current function of gases is entirely familiar. It has been clear for some time that if in transmission any dissipation is produced at a rate higher than the square of the current or voltage, for a given power, continuous waves with their small amplitudes will be likely to have an advantage over damped waves. The existence of a type of energy loss such as this would be seems entirely speculative as yet, however.

# THE INFLUENCE OF ALTERNATING CURRENTS ON CERTAIN MELTED METALLIC SALTS*

By C. Tissot

My attention has been directed to certain novel points in connection with the conductivity of several melted metallic salts and to the variation in conductivity caused by alternating currents ("electric oscillations").

The observations were made on the following salts: Chlorid of lead, chlorid of thallium, bromid of cadmium, chlorid of silver, bromid of silver, iodid of silver, acetate of silver. All the observations were made on salts which were in the solid state; that is, salts which were first melted and then cooled nearly to solidification.

To perform the experiments, there are placed parallel to each other in a porcelain dish, and at a separation of about 1 mm., two sheets of platinum about 4 or 5 mm. long and bent at right angles. A refractory material is piled up around these sheets in such a way that only the space between the sheets is left open in the dish. This space is then filled with the salt which is to be studied, and the dish is then heated over a good Bunsen burner so as to melt the salt. After the fusion and re-solidification of the salt, a lozenge of the salt will be found to adhere closely to the electrodes. An alternative, and nearly as satisfactory method, is to place a large drop of the melted salt on one of the sheets. This drop will spread if the sheet is heated, and the other sheet can be conveniently stuck to the same drop, if the second sheet is also properly heated.

These two methods of operation yield resulting sheets of salt which differ only in thickness. They behave similarly when current is applied.

After the salt has solidified, the sheets of metal are inserted as electrodes in a circuit composed of several storage battery cells, a device for reducing the electromotive force, and a galvanometer furnished with appropriate shunts. For all the salts mentioned above the general appearance of the phenomena is the same.

Under the conditions mentioned, and at ordinary temperatures,

* Delivered before The Institute of Radio Engineers, February 4, 1913.

these different salts have a resistance of the order of magnitude of a megohm. This resistance does not change so long as the applied potential difference does not exceed a certain value (of the order of about a volt). But if this potential difference is increased slightly above the critical value, the resistance of the salt diminishes somewhat, at first slowly, and then more and more rapidly. The increase in conductivity proceeds more quickly in proportion as the applied voltage is higher.

In cases where the thickness of the layer of salt is about 1 or 2 mm., the true conductivity is established only after several minutes. (For example, in the case of chlorid of lead under an applied voltage of 10, after 15 or 20 minutes.) In those cases where the layers of salt are considerably thinner, the true conductivity appears much sooner under an applied voltage of 1 or 2; e.g., after about 2 minutes. The resistance of the salt passes then from a value near a megohm to a value of several thousand ohms.

Instead of applying a constant difference of potential to the melted salt and waiting till the true conductivity appears, which, as has been seen, takes a certain time, one may hasten the final condition by applying a gradually increasing difference of potential. A value is thus very quickly reached for which the conductivity appears to be established rapidly.

In one way or the other, once conductivity is established by the application of the difference of potential, this difference of potential may be considerably reduced (without completely removing it), and yet the values of the galvanometer deflections will be simply reduced in the same ratio as the voltage is diminished.

It sometimes happens that in passing from a considerable difference of potential to a much lower value, that the acquired conductivity disappears. But this does not occur if one takes the precaution of reducing the applied voltage gradually. The applied difference of potential may thus be reduced to a fraction of its original value, say to several tenths of a volt, and still the layer of salt will remain conducting.

In all cases, no matter what be the value of the difference of potential applied to the salt layer, *once the conductivity is established, it may be made to disappear immediately by applying to the salt "electric oscillations" (alternating currents) of sufficient intensity.*

In order to permit these free alternating currents to act on the system, it may be excited by a distant spark from an induction coil or simply by the "break" spark of a buzzer. The salt layer

may also be inserted in place of the detector in a radio receiving circuit. A "decohering" of the system will be produced at the passage of each train of waves. The expression "decohering" which I have here employed is not intended to indicate the nature or mechanism of the effect produced. I simply intend to state that the system, when acted on by free alternating currents of radio frequency, behaves in the opposite way to a coherer; that is, there is an *increase* of resistance.

After the decohering has been produced by the alternating current, a steadily applied potential will cause the system to become conducting again. The growth of conductivity occurs gradually in general, as has been described above, but much more rapidly than previously. And, as before, the higher the applied potential difference, the shorter the time for the conductivity to be produced. Furthermore, the lower the value of the steady electromotive force applied to the system at the instant that the alternating E. M. F. is applied, the lower the value of the alternating E. M. F. required to produce the decohering.

By regulating properly the value of the applied potential difference (taking account of the intensity of the alternating current received), it is possible to cause the decohering which occurs when the oscillations cease to be practically instantaneous, that is, sufficiently rapid to permit registering signals. The arrangement given is therefore a new type of detector. I hasten to add, however, that there is no danger of the replacement by it of the excellent types of detectors now known, because of its smaller sensitiveness—at least there is no danger of the replacement of the excellent types of detectors now known by it, because of its smaller sensitiveness—at least in the present crude form. Be that as it may, and leaving aside all question of a practical application, the phenomenon, because of its general character, merits attention.

I shall therefore present some details as to the manner in which the separate salts which I have examined behave. The haloid salts of silver deserve mention because they are very satisfactory experimentally, being easy to obtain in a pure state and readily melted in air without decomposition. They have the further advantage of adhering well, after fusion, to the platinum electrodes. However, it was not with the silver salts that the phenomenon in question was first observed, but with chlorid of lead. After having proven the increase of conductivity of chlorid of lead under the action of a gradually increasing voltage, the haloid salts of silver, and particularly the chlorid, were investigated in the hope of avoiding the possible effects of polarization. We were aware of the work

of F. Le Blanc and Kerschbaum* who made some observations on chloride of silver which were quite similar to our own (neglecting the subsidiary question of the effects of electric oscillations).

We substituted for the platinum electrodes sheets of silver, and to our great surprise, failed utterly to obtain the results desired. The system made up of chlorid of silver which had been melted and connected between sheets of silver behaves entirely like a metallic conductor.

If a section of the salt between the electrodes is made, it is found that it is made up of thin bright sheets of metallic silver buried in an excess of the melted chlorid. This effect is not produced unless the chlorid is in contact with the metallic electrodes (of silver) for some time while it is melted. It is as if the chlorid when melted was *reduced* by the electrodes of silver. Gladstone and Tribe have observed and described this phenomenon. But it is probable that this is not a case of reduction of the silver salt but rather of a solution of the silver in the melted salt. On solidification, the silver crystallizes out of the salt forming links of a conducting chain thruout the mass. To avoid this objectionable effect, it is only necessary to work sufficiently rapidly so that the melted salt is not in contact with the silver electrodes for any length of time. If this is done, we obtain a system which behaves exactly as in the case of the platinum electrodes, thus showing that the phenomenon in question is not due to polarization.

On the other hand, with certain salts where a strong polarization is produced, the diminution of resistance due to the passage of a direct current is not produced. Such is the case with iodid of mercury. This salt melts without decomposition but with partial volatilisation. It has a yellow color when hot, which changes to red on solidification. It is thus easy enough to obtain a lozenge of this salt between the platinum sheets. But the conductivity of the salt, which is relatively large even at ordinary temperatures, diminishes continually under the action of an applied difference of potential. In no case have we been able to produce with mercuric iodid the phenomenon of "cohering" under the action of a direct voltage or of "decohering" by means of oscillations.

In the present state of our knowledge, any attempts at an explanation seem premature. It will be seen that the salts investigated fall in widely different classes. The effect is certainly not peculiar to chlorid of silver (or the haloid salts of silver) as F. Le Blanc seemed to think. For it can be equally well produced with a

* F. Le Blanc and Kerschbaum, "Zeitschr. für Elektrochemie", 1910, pages 242 and 680.

number of salts of other metals. I should like to mention with particular stress bromid of cadmium, which gives exceedingly regular results. As I used bromids and chlorids at first, I thought that these elements of the halogen group might play an essential part. This opinion was not well founded, however, for I have apparently been able to produce the same effects with silver nitrate, the acid radical of which contains only nitrogen and oxygen.

It may be that we have something analogous to the variations of conductivity of certain solid salts which Baedeker* has mentioned. It is known, particularly, that iodid of copper, which is ordinarily a poor conductor, becomes a good conductor when it is placed in an atmosphere of iodine vapor. Another experiment may be suggested; namely to observe the behaviour, when slowly heated, of the various salts which have been experimented with, a continuous current at the same time passing thru them.

Even a slight heating has at first the effect of making them better conductors. In general, the effect is temporary, and disappears on cooling. But if one heats them sufficiently, the conductivity obtained persists after cooling; heating has accelerated "cohering."

Even tho these experiments have treated only in an indirect way the matter of the detection of electric oscillations, I have made them public in the hope that they will suggest to the physicists who are working in the field of radio communication some interpretation applicable to other detectors.

**(Translated from the French by the Editor.)**

Paris, October 28, 1913.

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## DISCUSSION.

**John Stone Stone:** This paper naturally suggests the "anticoherers" of the earlier days of radio communication. For example, S. G. Brown's detector, consisting of a lead point resting lightly on a lead surface which had been peroxidized, behaved similarly. Later he employed an "electrolytic" type, consisting of a lump of lead peroxid between a sheet of lead and a platinum point. The forms of detector described are also somewhat like the de Forest "Goo" detector, which consisted of a tube containing a fine metallic powder in glycerin. Before the International Electrical Congress at St. Louis, Dr. de Forest stated in

* Baedeker: "Die elektrischen Erscheinungen in metallischen Leitern," 1911, page 23.

his 1904 paper that metallic chains were formed by a small direct current passed thru such a tube, and that these chains were broken up by the radio frequency currents, thereby causing a marked increase in resistance. The chains were rebuilt by the direct current shortly afterward. The effects produced are similar to those described by Tissot, but there is a question as to the resemblance in the ultimate mechanism in the two cases.

**Robert H. Marriott:** This paper indicates one interesting possibility. If it can be shown that the indication produced depends (with detectors of the type described by Tissot) on the thickness of the salt layer and the applied electromotive force and the received energy, and on nothing else, then it might be possible to use the device for measuring received energy accurately. In connection with the recording of the strength of "atmospherics," this would be quite useful, for it gives rise to the possibility of recording the strength of such disturbances on a chronograph sheet.

It might be possible, using a small quantity of the salt, to increase the sensitiveness of this device markedly, and make it more valuable commercially as well.

It is extremely gratifying that the Institute should receive papers from such eminent investigators as M. Tissot, in view of the increasingly international character of the Institute.

**John Stone Stone:** Mr. Marriott has called attention to an important point. A sufficiently thin film of the salt would probably permit of a marked reduction in the minimum radio frequency electromotive force producing indications, and would give high sensitiveness. A practical difficulty appears, however. After raising the direct electromotive force and current, it must again be reduced to a very small value for sensitiveness. Therefore the radio frequency electromotive force may have to be actually large enough to bring the resultant current back to zero, thereby allowing the cell to "snap back" to its high sensitiveness.

**Julius Weinberger:** There seems to be a certain relation between this device and the crystal rectifier.

I suggest that, in cooling the salts and electrodes, cool them at different rates, so as to produce interstices between the electrodes and resulting imperfect contact. This will probably increase the sensitiveness and make the response quantitative as well.

**John Stone Stone:** The cell might be made between plates in such a way that in cooling, only the contact surface of the fused salt was strained.

The paper indicates that some salts are unreliable in their action and others are noted as reliable. I have worked with selenium cells, and in their earlier forms some were extremely unreliable, but such cells have since been made very reliable. It may prove possible to do the same in this case.

**Julius Weinberger:** If we take the expression of Dr. Tissot, "cooled nearly to solidification," to mean that the salt is still in a semi-liquid, viscous state, with no evidences of crystallization present, another explanation for the action of the cell could be conceived.

In such a viscous state electrolytic conduction of direct current would be quite possible; however, ionic action must necessarily be slow; that is, attended with considerable inertia. The fact that electrolytic conduction exists is borne out by Dr. Tissot's observation that the resistance of the cell is lowered as the applied D. C. potential is increased, until a constant resistance is reached; and this is a characteristic of electrolytes. Now, as the radio frequency oscillations are applied they travel mainly over the surface of the viscous mass of salt, and since the conductance of the cell is electrolytic in nature, and since ionic action is already inseparable from some inertia, the ions of the salt will remain practically at a standstill when subjected to the rapid reversals of the radio frequency current.

Thus, the surface of the salt, at least, will, to all intents, become an insulator while the oscillations are passing. An insulating film is therefore thrust between the two electrodes and the direct current ceases to pass. As the oscillations are stopped, however, ionic conduction of the direct current again slowly starts, and the salt assumes its lower resistance.

**John Stone Stone:** I think that polarization of the cell is still a possibility.

**Julius Weinberger:** Pierce has shown that, under many conditions, there is no polarization with crystal rectifiers.

**John Stone Stone:** But such cells as those considered are made up of amorphous material.

**Julius Weinberger:** Not necessarily; crystals may be formed in cooling.

**John Stone Stone:** Such crystals as are formed in this cell are not dehydrated, thereby still permitting polarization of the usual sort.

**Emil J. Simon:** Does the conductivity of such cells fail to follow Ohm's law?

**John Stone Stone:** Not at all.

**Emil J. Simon:** This effect is analogous, possibly, to the ionized gas effects. We can also get a large change in resistance accompanying a small change of electromotive force in that case.

**John Stone Stone:** More data is required to enable us to judge whether the resistance of the cells is sufficiently critical to furnish an "unstable" condition. If such instability were sufficiently marked, and the inertia of the cell were low, we could get the "singing arc" effects.

**Emil J. Simon:** The trigger action of such cells might be of value.

**John Stone Stone:** Yes, provided that the response was reasonably quantitative.

**Robert H. Marriott:** Carborundum shows the same decrease of resistance on high electromotive force, but its resistance does not remain low when the electromotive force is reduced.

**John Stone Stone:** That is true, and ionized gases show the same effect. The rate of such changes may be very high in gases, thereby providing the necessary conditions of instability and for sustained oscillations, under suitable circumstances.

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Mr. Stone then described briefly the nature of the apparatus which was used in the Paris-Arlington transmission in connection with the time-difference tests. Professor Abraham, of Paris, had given him the details of the photographic receiver. In this photographic recorder, the moving or driven element was the film and a tuning fork of known pitch recorded the time on the film. A special galvanometer was used to receive the Paris signals, a narrow beam of light reflected from the galvanometer mirror, and passing thru a suitable lens giving a sharp moving image. The distance from mirror to film was large, considerable amplification being secured. The average signals received extended just above the zero line, but sometimes the deflection of the galvanometer was so great that the signals ran completely off the tape. The spark frequency at Paris was 60 to the second, and a separate image was produced on the tape for each one. The tuning fork in question was free, not being driven electrically, and thus highly accurate timing was secured. The procedure was as follows: At a given

time Paris began transmitting. The signals were received slightly later. A specified time after the receipt of the signal Washington began sending the return signals. This operation was repeated many times and the average difference between the *total time* and the *time interval* between transmission and reception at Washington gave the time required for the transmission itself. A large number of observations were made to reduce the probable error. So far no difference was found between the results of rough computations of the velocity of transmission and the known velocity of light.

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**Lester L. Israel:** Conceiving the fused salt to be either a solid solution of some of the metal in the salt, or to have some of the properties of an electrolyte, it follows that during passage of direct current, metal would be deposited at points of heterogeneity (also probably at points of high resistance), thereby lowering the resistance. Since the deposited metal particles are minute, they would redissolve (or recombine chemically) comparatively rapidly. Thus, while the current is below a critical value, the metal deposited would be rich and the resistance high. Above this critical value of current, the rate of deposition exceeds the rate of solution and the deposited metal lowers the resistance. Bringing the E. M. F. back to that which established the original critical current does not reduce the current to the critical value so that the resistance remains low. The radio frequency wave opposing the direct current brings the current below the critical value, solution exceeds deposition, and the original high resistance becomes established. Or it may be that the deposited metal is a "saturated solute," and is suddenly redissolved on the application of radio frequency energy somewhat as mechanical vibration will cause a supersaturated solution to crystallize.

# EFFECT OF A SHORT-CIRCUITED SECONDARY ON AN OSCILLATING CIRCUIT.

By Louis Cohen.

(Reference to a further discussion on Frederick A. Kolster's paper, "The Effects of Distributed Capacity of Coils Used in Radio Telegraphic Circuits.")

It will be noted that on pages 32 and 33, of Volume I, Part 2, of the Proceedings of the Institute of Radio Engineers, the effect of short-circuiting a number of turns of the secondary of an inductive or direct coupler was discussed. In an article printed in "The Electrical World" for November 1, 1913, page 899, Mr. Louis Cohen discusses this question mathematically and reaches conclusions of interest to the readers of the above paper. A reprint of the same article by Mr. Cohen appears in "The Electrician" for January 23, 1914, page 652.—(Editor's Note.)

# THE GOLDSCHMIDT SYSTEM OF RADIO TELEGRAPHY*

By Emil E. Mayer

The problem of producing very high frequency energy by electrical machinery has aroused great interest ever since the beginning of the development of radio telegraphy. To its solution have been contributed much inventive thought and engineering skill. I need only recall to you the names of Nikola Tesla, Reginald Fessenden, and E. F. W. Alexanderson.

So far as obtaining large amounts of energy is concerned, the first to arrive at a practical solution of the difficulties was Professor Rudolph Goldschmidt, former Chief Electrician of the English Westinghouse Company, and Professor of Electrical Engineering at the Technical College of Darmstadt. Some of his large generators, which furnish an antenna output of 150 kilowatts, have now been in operation for almost a year, and the results obtained are quite unusual.

## Principles of the Goldschmidt Alternator.

The principles used by Goldschmidt are as ingenious as they are simple.

1. The non-rotating part of an alternator may be excited by an alternating current. Since the time of Ferrari, it is well known that the magnetic field produced by an alternating current may be resolved or split into two separate fields, each of half the amplitude. These component fields are to be regarded as rotating in opposite directions with the same frequency as that of the exciting current. To understand this, we need merely consider that every north pole changes into a south pole (with a sinusoidal variation); and that at the middle of this variation the magnetic field is equal to zero.

2. If a rotor revolves in the field of the exciting alternating current, two electromotive forces are produced in its windings. Calling the initial frequency $n$, and the frequency of the rotor $n_1$ it is obvious that the frequencies of the electromotive forces produced in the rotor are $(n+n_1)$ and $(n-n_1)$. If the revolving parts rotate synchronously, that is, if $(n-n_1)=0$, the frequencies produced are $2n$ and 0. We can thus explain the well known fact that by

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simply adding a number of such machines on the same shaft, the field of each being excited by the current produced by the preceding one, the frequencies of the currents produced will increase in arithmetical progression.

3. The ingenious process of producing this continuous increase of frequency in *one* machine was the invention of Goldschmidt. If a current of frequency $n$ is permitted to flow in the rotor, it will produce a magnetic field of the same frequency. If the stator is appropriately wound, there will be produced in it, in turn, the frequencies $(2n+n)$ and $(2n-n)$ that is $3n$ and $n$. Obviously, so far as the mutual induction between them is concerned, it makes no difference which of the parts is the exciter, or which the rotating portion. The current of frequency $3n$ in the stator will produce a magnetic field, which will excite electromotive forces of frequencies $4n$ and $2n$ in the rotor windings. If the process is continued for five frequency transformations, or "reflections," electromotive forces of the following frequencies will be produced:

| *Stator* | *Rotor* |
|---|---|
| $n$ | $2n$ and 0 |
| $3n$ and $n$ | $4n$ and $2n$ |
| $5n$ and $3n$ | $6n$ and $4n$ |

4. It is not necessary to provide separate windings for the currents of different frequencies, for they will all flow in the same stator or rotor windings provided they find an appropriate closed circuit.

As an example of this effect, the well-known fact may be cited that in the direct current exciter circuit of an ordinary single phase alternator there is an alternating current of double the fundamental frequency superposed on the direct current. This double frequency current has been produced in the way described, and had found its way over the commutator of the direct current exciter.

5. In dealing with the frequencies used in radio telegraphy, a simple short circuit is not the circuit of least impedance, for even a small piece of cable has considerable inductance and a very small capacity, which, when added to the inductance of the winding itself will make the reactance of the circuit

$$\left(2\pi nL-\frac{1}{2\pi nC}\right)$$

high even if the ohmic resistance is neglected. To have minimum impendance, particularly at such very high frequencies, the cir-

cuits must be so tuned that the effects of inductance and capacity balance each other, that is,

$$2\pi nL = \frac{1}{2\pi nC}$$

In this case, only the ohmic resistance, which is naturally made as small as possible, remains.

By properly tuning the circuits containing the inductance of the armature, currents lagging behind e. m. f. are avoided; and the only limits to the growth of current are the ohmic resistance of the circuit and the losses due to hysteresis and eddy current as well as losses in the insulating material. These latter losses may be summed up in a single resistance factor, properly calculated.

If in all the circuits electromotive force and current are in phase, the frequencies of the *same* magnitude produced by rotation in two *different* magnetic fields must be in *opposite* phase, and therefore cancel each other to a certain extent. They may be simply considered as action and reaction. For example, there is obtained by rotation in the field of the rotor current of frequency $2n$ another current of frequency $n$; that is, of the same frequency as the fundamental current. But the frequency $2n$ has been produced by rotation in the field of the original current of frequency $2n$. So that the current of frequency $n$ produced by rotation in the field of frequency $2n$ will be in exactly opposite phase to the original current of frequency $n$, and will therefore reduce its magnitude. Experiments shows that if all the circuits are properly tuned and connected, only a very small margin of the intermediate frequencies will remain. The intermediate frequencies will exist in only sufficient amount to cover the losses in the tuning circuits and that portion of the loss in the machine which is necessarily due to the definite frequency considered.

The process of increasing the frequency can be stopped at any point merely by not adding any further tuned circuits to those already present, for no currents of the higher frequencies will flow without tuning.

As regards the magnetic fields, a similar phenomenon occurs. Only the magnetic field of the highest frequency will exist in its full intensity, for all the intermediate frequency fields will be partially neutralized. Therefore only the last field will add noticeably to the hysteresis and eddy current losses.

The Goldschmidt alternator, built as described, is a combined generator and frequency transformer. It is remarkable that theoretically the process of energy transformation to the higher

frequencies takes place in such a way that all of the generated energy is transformed. The limit of the "reflection" is determined solely by the copper losses, and the losses in the iron and insulation of the machine; if we consider efficiency only. If actual output for a given amount of exciting energy is considered, the limit is reached when the magnetic leakage between the rotor and stator becomes excessive. Since the influence of the leakance will be to decrease the output per unit of exciting current at each reflection, it is of the highest importance to keep it small.

The diagram of connections (Figure 1) shows a Goldschmidt alternator with four frequency-transforming circuits. For each

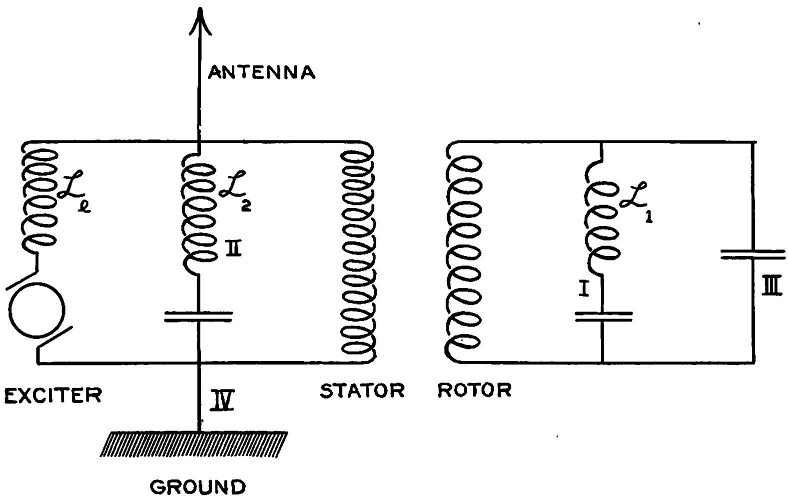



FIGURE 1—Connections of Goldschmidt Alternator.

frequency there is a tuned circuit. The exciter circuit, and also the circuit of the lowest frequency are protected against the higher frequency currents by additional inductances, or choke coils. As can be readily seen, this measure is necessary to render tuning feasible.

It is necessary that there shall be a certain relation between the inductances in the tuning circuits for, say, the third and fifth frequency currents produced in the stator. If this relation is not obtained. the addition of a further circuit in the tuning process would detune the other circuits so considerably that it would be exceedingly difficult to tune again. It is clear that, however, we adjust the tuning circuits, a certain detuning will occur under the conditions. But if the inductances are properly chosen, this detuning can be easily calculated and allowed for.

## GENERAL NOTES ON THE DESIGN.

It has already been stated that every process of reflection involves certain losses which are due to losses in the tuning circuits and also in the machine itself; and further, that the obtainable energy becomes less at each process of reflection because of magnetic leakage between the circuits. This fact makes it desirable to reach the highest frequency (which is to be used for radio telegraphy) without having more than, say four or five reflections in the machine. Consequently the designer is forced to use an unusually high fundamental frequency. For example, the wave length of 6,000 meters, which is frequently used for trans-Atlantic work, corresponds to a frequency of 50,000 cycles per second. (These quantities are connected by the equation $\lambda = \mathrm{v}/n$ where $\lambda$ is the wave length, v the velocity of light, and $n$ the frequency.) If not more than five reflections are to be permitted, the initial frequency must be 10,000 cycles. Consequently a high speed and a large number of poles are necessary. Let us assume a maximum speed of rotation of 3,000 revolutions per minute. Then, as the following equations show, we must have 400 poles.

$$\frac{\mathrm{P\,U}}{120} = n$$

where P is the number of poles, U the revolutions per minute, and $n$ the frequency.

Using the best materials and the highest engineering skill, the maximum speed which can be safely maintained is 200 meters per second at the periphery. This is already rather unusual, but, as experience shows, it is permissible, if proper precautions are taken. We find therefore, that for 3,000 revolutions per minute, the greatest diameter of the rotating portion of the machine must not exceed 1.25 meters (4 feet 1 inch). This gives a circumference of 400 centimeters (12 feet 10 inches). Consequently, the width of each pole is 1 centimeter (0.4 inch). If account is taken of the necessary iron and insulation, it will be seen that we are limited as to the current which can be carried by the conductor in each slot.

To save room and to avoid capacity and inductance between parts of the winding, the safest and most economical method is to place only one conductor in each slot; that is, one winding per pole. To make it possible to adapt the voltage produced to the

resistance of the antenna which is employed, the winding is arranged so that it can be divided into groups which can be arranged in series or parallel. The wire itself must be stranded, and the strands must be the finest the manufacturers will consent to use. For example, a number of Number 40 B. & S. gauge wires, each separately insulated and properly stranded, will prevent undue losses due to the skin effect. In addition, the outside insulation of this wire must be very reliable. In Figure 2 is shown a simple diagram of the winding of the rotor and stator.

Iron which is in a magnetic field of frequency of 30,000 or 40,000 cycles must be of the best quality and very well laminated. In addition to high mechanical strength it must have a large

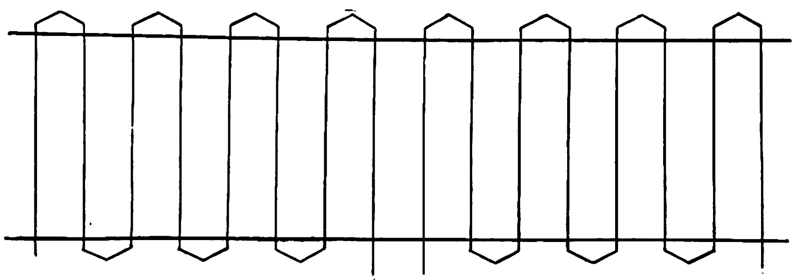


FIGURE 2—Winding Diagram of Rotor and Stator.

ohmic resistance to keep the eddy currents small. Eddy currents not only produce heat losses, but also weaken the magnetic fields by the reaction of their own fields. They will, therefore, decrease the output of the machine. In our machines we use steel of a thickness of 0.05 millimeters (or 2 mils = 0.002 inch) insulated by paper about 0.03 millimeter thick (1.2 mils). It will be seen that the body of the rotor and of the stator are more than one-third made up of paper, and the combination is a rare one to be used as a construction material of high quality. It is needless to say that an enormous amount of detail work and experimenting were necessary before it became possible to subject a rotor made of such materials to the strains arising at a speed of 200 meters per second. Great credit must be given the manufacturers, Messrs. Bergmann, of Berlin, for the ingenious manner in which they worked out every detail of this machine.

I feel that I am not speaking too strongly if I state that I believe that we shall consider the construction of these very high frequency machines as marking the beginning of a new era in engineering exactitude. For we have here an extremely large and heavy machine, which must be built with the precision of a

watch. Consider, for instance, the air gap. We have seen the great importance of a low stray factor. This stray factor will depend almost entirely on the size of the air gap, for this is practically the only region of any marked reluctance to the magnetic flux. Therefore this air gap is made 0.8 millimeter wide; that is, a trifle more than 1-32 of an inch. This clearance, in combination with a peripheral speed of 200 meters per second for a rotor weighing about five tons, forces the manufacturer to adopt absolutely new engineering methods.

Another example of the unusual precision required is the following. In any electrical machine the slots must be approximately parallel, but in this particular case a divergence from parallelism of 1 millimeter in 1 meter's length causes 20 per cent. of the total output to disappear.

All of these effects could be foreseen, and were guarded against. We shall consider an unforeseen special difficulty which arises when handling such a large current at very high frequencies in a machine. This trouble arose at the slip rings. It is necessary to connect the ends of the rotor windings to slip rings in order to make it possible to attach the tuning circuits. In order to avoid having an excessively high voltage in the rotor, Goldschmidt placed a number of the rotor windings in parallel. Consequently the current flowing in the rotor was very high. A large number of brushes were put on to handle this current, but the current would not distribute itself equally between the various brushes. As soon as full load was put on, some of the brushes would heat and spark, while others would not. We soon found that because of the additional resistance of the particular circuit in which it was placed the impedance of that path would be considerably increased, and the brush in question would not take its share of the total current. Furthermore, if because of some unavoidable unevenness in the surface of the slip ring, one of the brushes was raised slightly, the current flow would not be interrupted, because the inductance of the circuit prevented a sudden change of current, the time constant, L/R, being large. As a result of this effect the slip ring would be burnt. A long time was required to find the necessary materials and design whereby these disadvantages were eliminated.

In addition, it was rather difficult to handle the currents outside of the machine. In usual power engineering the capacity of the windings of the machine to ground is of importance only in connection with certain transient phenomena such as occur when closing circuits or at a short circuit. This capacity plays

a very important part in high frequency machines. A portion of the current which has been produced will escape to the ground thru this capacity without being usefully employed in producing the higher frequencies or being sent into the antenna. Under the worst conditions, the capacity to ground of the windings and the inductance of the iron paths from winding to winding or from windings to ground will combine to produce a resonant effect for currents of some one of the frequencies produced, with the result that the current itself will pass partly through the iron of the machine. In such a case it would be impossible to get the expected output even if the excitation be abnormally increased.

### Excitation of the Alternator.

Because of the ease of handling it, direct current proved most suitable for use in excitation.

In radio telegraphy, it is necessary to vary the energy sent into the antenna rapidly in accordance with the signals (dots and

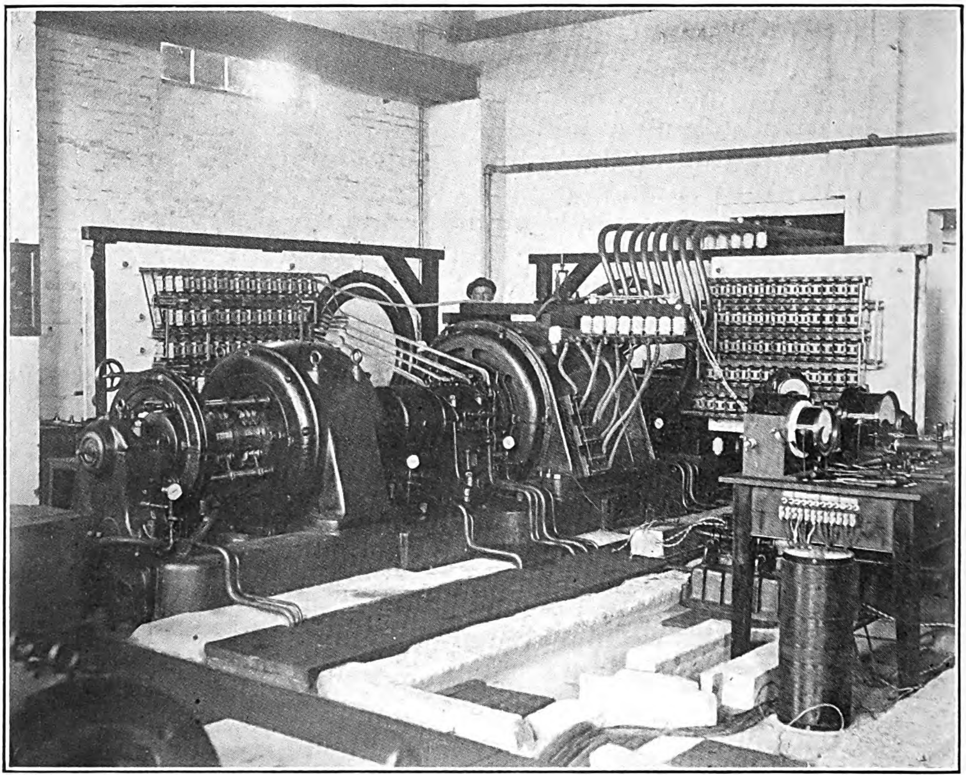


Figure 3—Goldschmidt 100 K. W. Radio Frequency Alternator.

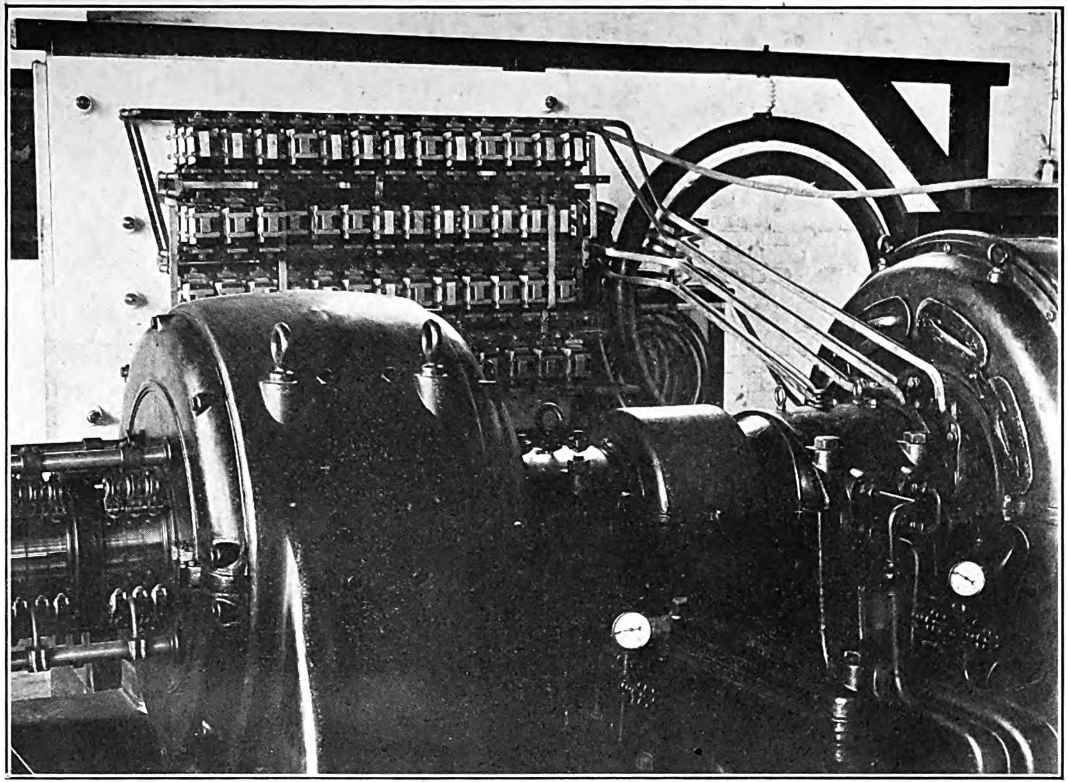


FIGURE 4—Driving Motor and Condenser Boards.

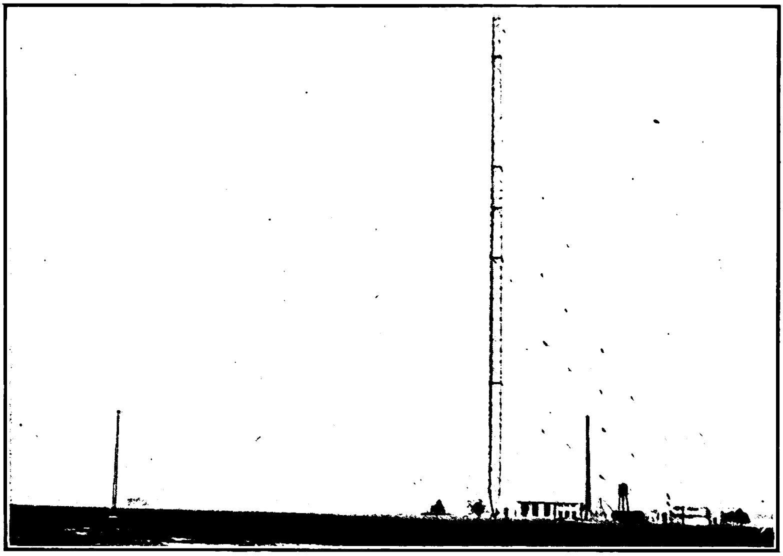


FIGURE 5—Tuckerton Radio Station, Showing 825 foot Steel Tower.

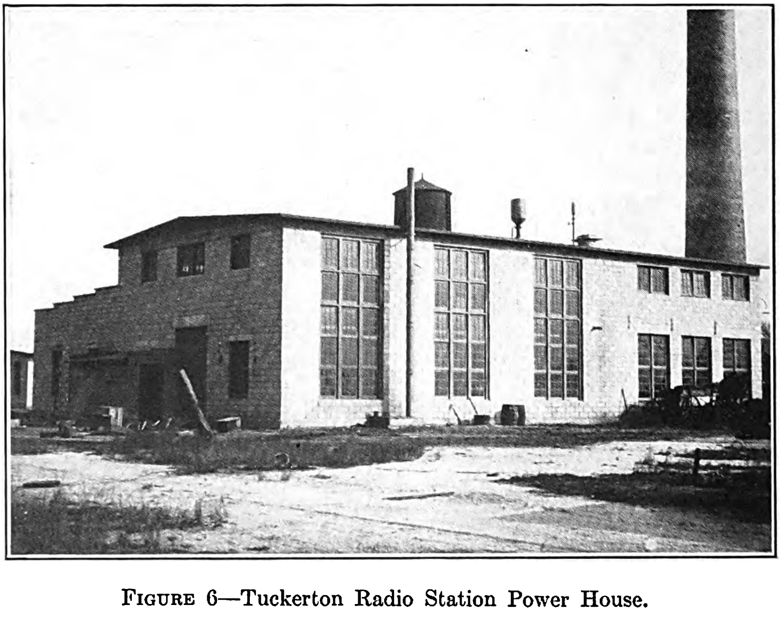


FIGURE 6—Tuckerton Radio Station Power House.

dashes) which are being sent. Assume, for example, an average speed of transmission of 30 words per minute, each word consisting of five letters of two signals each. We have, then, 300 signals, or 300 makes and breaks per minute. It is therefore vastly preferable to govern this energy flow in the exciter circuit, where the amount of energy to be controlled is so much smaller. The exciting energy is between 5 and 10 kilowatts for an output of from 100 to 200 kilowatts from the machine.

The phenomena which occur when the exciter circuit is closed are of interest. It is obvious that before reaching the final state, there will be damped oscillations having a time constant L/R.

FIGURE 7—Eilvese Radio Station Power House.

These free alternating currents are represented by an equation of the following kind:

$$i = I_m\left(1 - \epsilon^{-\frac{R}{L}t}\right)$$

We see that it is desirable to choose large capacities and small inductances for the tuning circuits, and that it might be advisable to insert additional resistance in the exciting circuit, or perhaps even in some of the other circuits to make the signals very distinct.

This might be the case for automatic transmission and automatic reception at high speed. With automatic transmission and

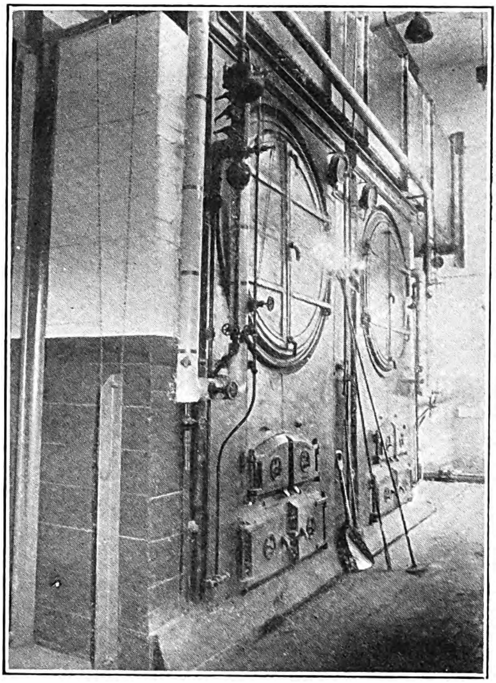


FIGURE 8—Tuckerton Radio Station Boiler Room.

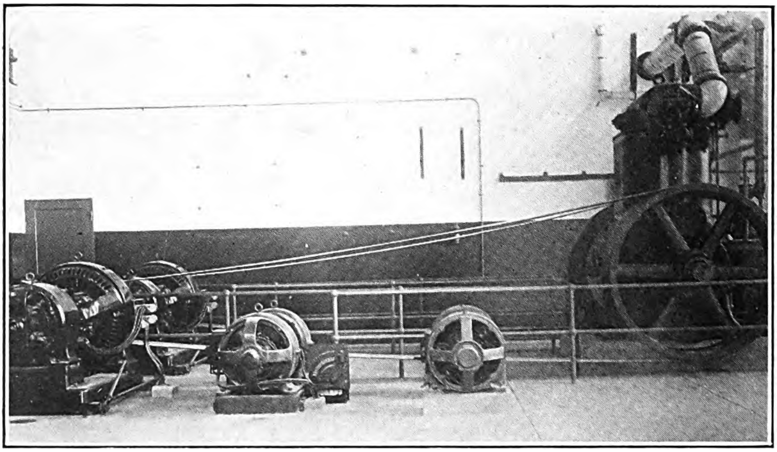


FIGURE 9—Tuckerton Radio Station Dynamo Room.

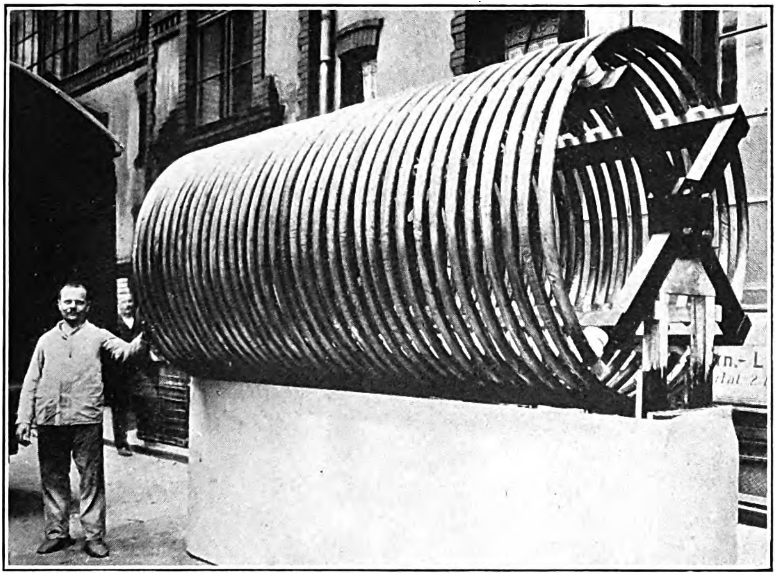


FIGURE 10—Antenna Loading Coil.

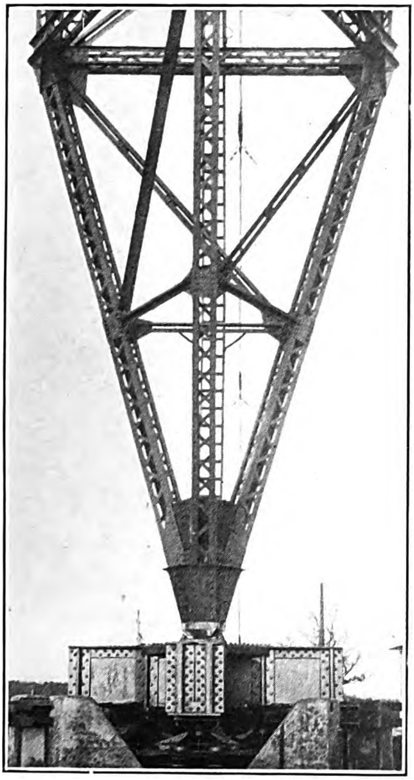


FIGURE 11—Base of Steel Tower Supported on Columns of Glass Insulators.

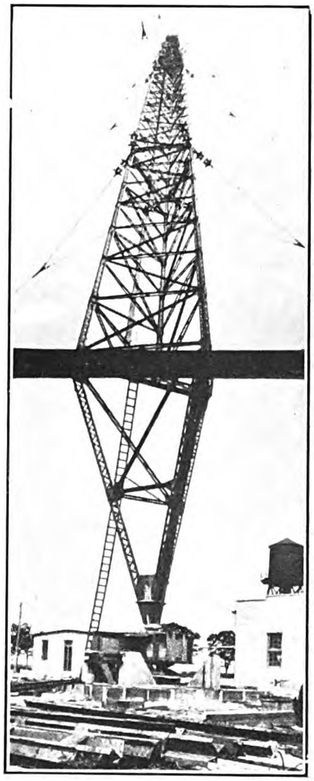


FIGURE 12—View Looking Up Steel Tower.

reception the number of makes and breaks per minute may be three times as great as in the case just described, and if the final state is not rapidly attained, the signals would not be distinct.

## TRANS-ATLANTIC RADIO COMMUNICATION.

Since April of last year, a Goldschmidt machine of maximum output of 200 kilowatts (normal output 100 kilowatts) has been in use at the German radio station at Neustadt-am-Ruebenbergen near Hanover, Germany. A point of interest in connection with this station, and also the nearly completed station at Tuckerton, New Jersey, is that they resemble a medium size power plant of the usual kind more than a typical station for radio telegraphy. The following illustrations of the machine and of the power house show this. (Figures 3 thru 9).

The antenna, with a loading coil of large dimensions, (Figure 10) is connected to the last tuned circuit of the alternator. The antenna output can therefore be readily measured by simply connecting a volt-meter across the antenna and ground, and placing an ammeter in the antenna. As an antenna, (Figures 5, 11, 12) we use a double cone wire system, consisting of thirty-six wires attached to the top of a steel tower 825 feet (250 meters) high. The outer ends of these wires are fastened to poles 40 feet (12 meters) high, which poles are placed in a circle around the tower, the radius of the circle being 1,500 feet (450 meters). The antenna itself is only about one-third of the length from the top of the tower to the surrounding circle of poles, and is supported by a chain of heavy saddle insulators. The tower is insulated from the ground, (Figure 11) and there is also an insulating joint in its middle. These separating insulators consist of a number of columns of glass insulators. Glass is used as an insulating material because it is satisfactory when used, as here, only under compression. The ends of the guy ropes which support the tower are fastened to reinforced steel beams which are sunk in heavy concrete foundations. They are shown in Figure 5.

It is unnecessary to describe the prime mover in detail. It may be of some interest to know that in Germany we use a 400 horse power "Wolf" engine which contains boiler and engine together. This engine meets the requirements of economical operation, small space required, and reliability of operation very satisfactorily.

The radio frequency machine is connected by means of a flexible coupling to a direct current motor, which draws its energy from two direct current generators in Ward-Leonard connection. By

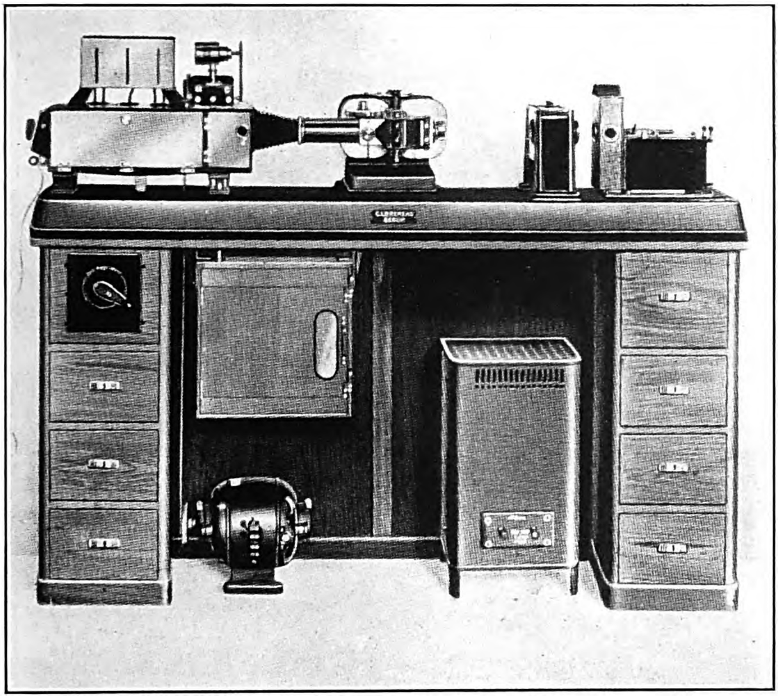


FIGURE 13—Photographic Printer for High Speed Reception.

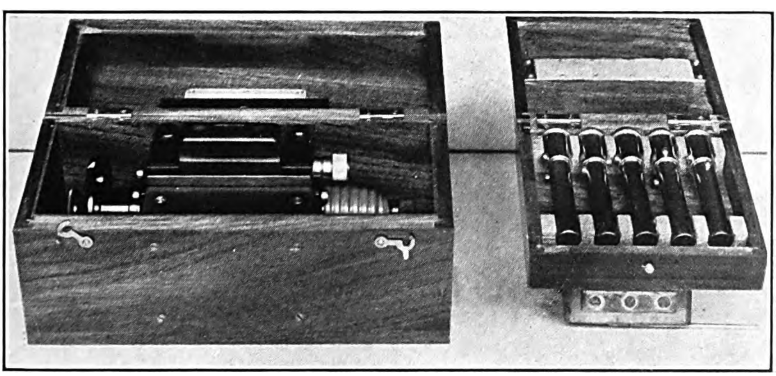


FIGURE 14—Vibrating Thread Cases and Holders for Photographic Printer.

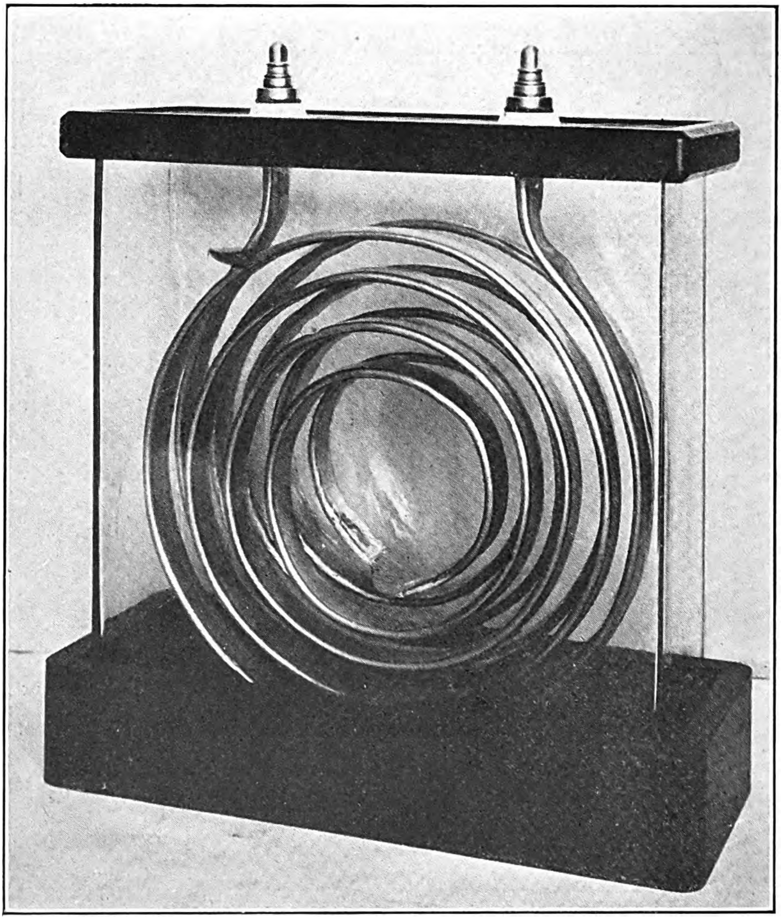


FIGURE 15—Twenty-five Microhenry Inductance Coil Unit, 200 Amperes.

regulating the voltage of the two Ward-Leonard dynamos, ease in starting and convenience in speed regulation are obtained.

The motor, which was built by Messrs. Bergmann of Berlin, is somewhat out of the ordinary. It is a 4,000 revolutions per minute, 250 horse power, 220 volt direct current motor.

The inductances of the tuning circuits, which must carry currents of about 200 amperes, are made of tubing, and are partly of the cylindrical and partly of the spiral pan cake type. Experiment and theory agree, however in pointing to properly made cylindrical coils are preferable.

Quite a discussion has arisen concerning the possibility of satisfactory speed regulation for such machines employed for radio

telegraphy under conditions of continuous and rapid variation from no load to full load. Certain individuals have feared that the inconstancy of speed might prove a serious drawback to the use of

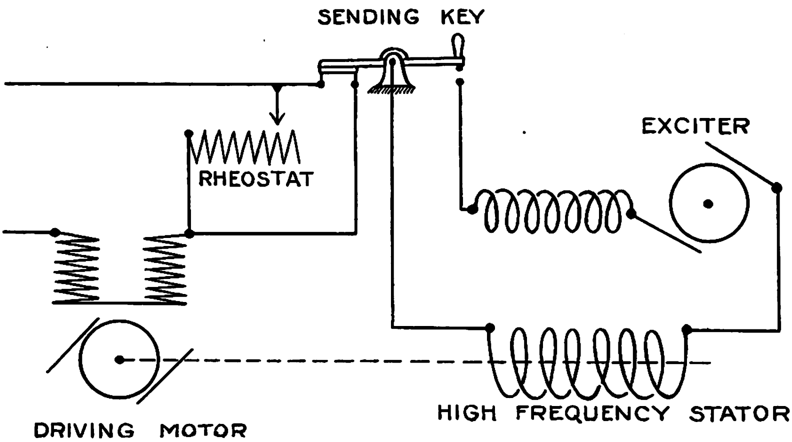



FIGURE 16—Speed Regulation Device for Driving Motor.

such alternators. Practice, however, has shown that speed regulation is really a very simple matter because of the influence of the enormous rotating masses which, thru their inertia, oppose any changes in speed. As an additional method of obtaining speed constancy, Professor Goldschmidt originated the design shown in Figure 16. While the sending key is open, a part of the field resistance of the driving motor is short circuited. This short circuit is broken when the key is pressed.

Theory shows that a slight variation in speed would, so far as transmission is concerned, have the effect of making the sustained waves equivalent to slightly damped waves. That is, the sharpness of tuning would be slightly impaired. However, we were unable to find any such effect in our tests.

### RECEIVING APPARATUS.

An important portion of the Goldschmidt system of radio telegraphy is the receiving apparatus, of which the most novel and important portion is the tone wheel. This is the simplest form of frequency transformer that can be imagined, and yet has an exceedingly high efficiency. For normal telephone reception, the problem is the following. The incoming waves, of a frequency of about 50,000 cycles, are to have their energy so transformed as to give rise to alternating currents of audible frequencies, say between 250 and 3,000 cycles per second.

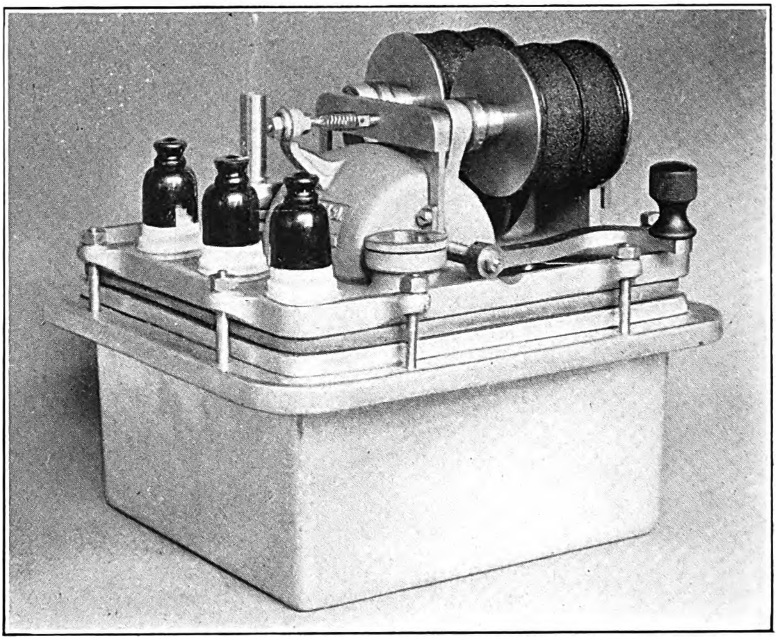


FIGURE 17—Sending Key.

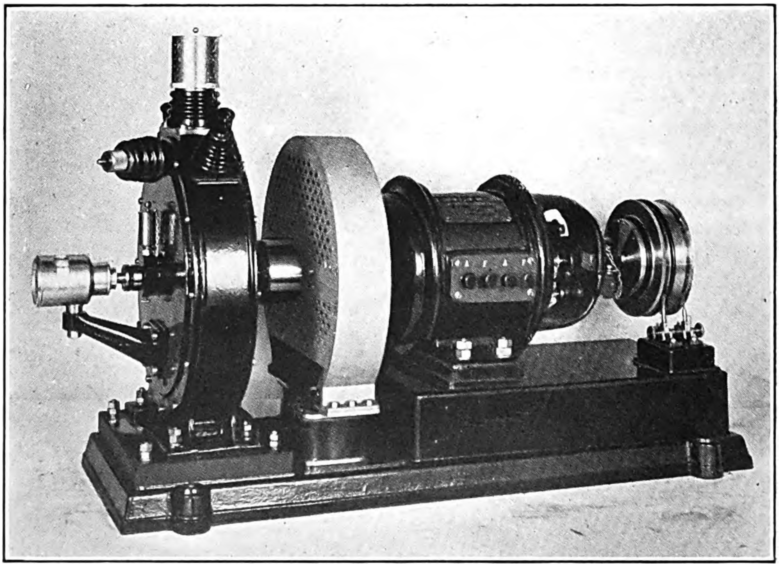


FIGURE 18—Tone Wheel, Showing Centrifugal Speed Control, Eddy Current Brake Disc, and Special Motor for 4,000 R. P. M.

The usual crystal, electrolytic, and magnetic detectors are capable of making only damped wave trains audible. For sustained waves, they react by giving a sort of click in the telephone receivers at the beginning and end of each incoming signal. The so-called "Tikker" of Waldemar Poulsen, a very sensitive detector for sustained waves, does not give a musical note in the receivers but only a sort of buzzing noise. Furthermore, it uses only a fraction of the incoming energy. The buzz produced is very similar to the sounds produced by atmospheric disturbances, (static) and make it very difficult to receive with the tikker if atmospheric conditions are unfavorable. The Goldschmidt frequency transformer transforms the incoming frequencies to a note of well defined frequency, and therefore gives a pure and musical tone. The principle of its operation is the following. A simple toothed wheel, acting as a make-and-break commutator, has such a number of teeth or poles that, at a reasonable speed its interruptions are synchronous with the incoming frequency. For example, 800 teeth on the wheel, and a speed of 3,750 revolutions per minute, would produce a frequency of interruption of 50,000 cycles per second.

The width of the teeth may be made equal to the width of the spaces between them. For the sake of simplicity in explanation, let us assume that the contact which slides on these teeth is merely a point (or line). If this device, running synchronously, is connected in any way to the receiving antenna, it will produce a pulsating direct current, for it will always make contact for just the length of a positive or negative half-period. The telephone diaphragm will not be displaced under the influence of this rapid succession of unidirectional impulses because of its mechanical inertia. Conse-

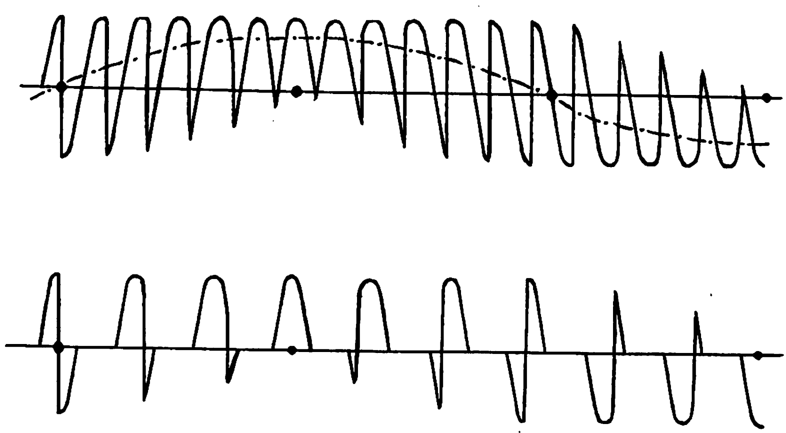


FIGURE 19—Current in Tone Wheel.

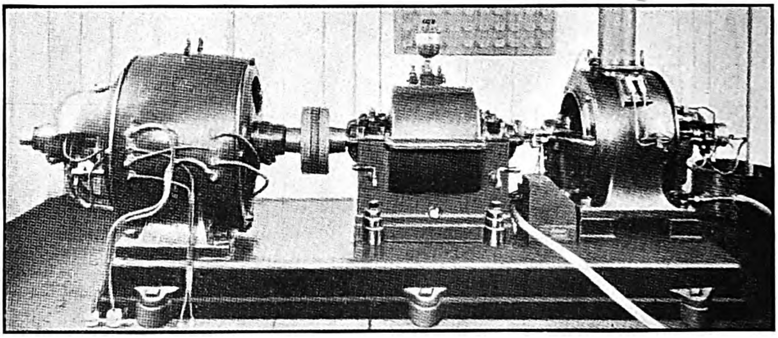


FIGURE 20—Ten K. W. Goldschmidt Alternator.

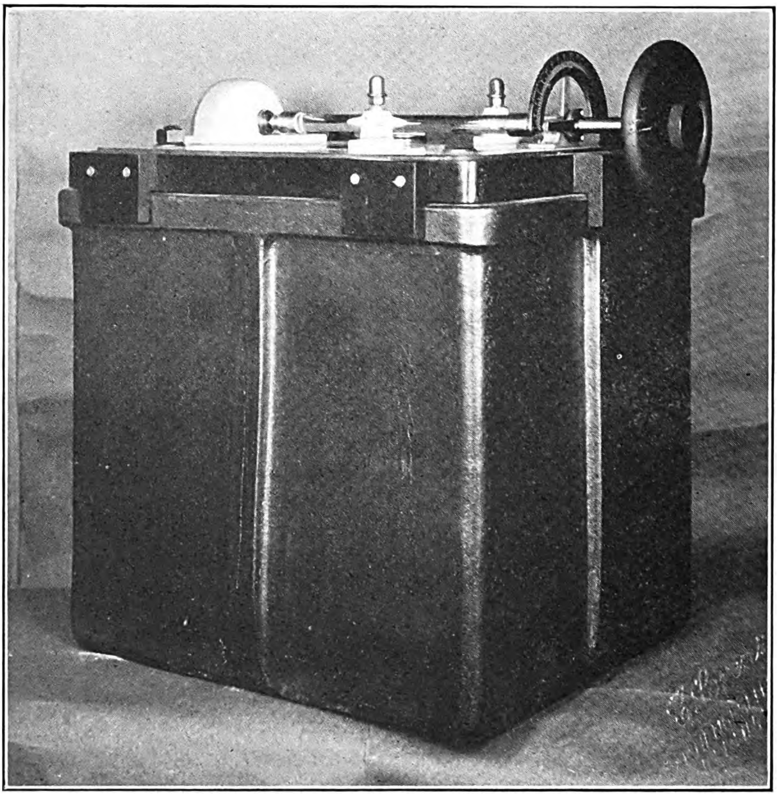


FIGURE 21—Antenna Variometer.

quently no sound will be heard. If now the speed be altered, so that the wheel runs slightly above or below synchronism, the full amount of energy of the positive half-period will be admitted to the receiver for only *one half period*, while for the next half period a smaller portion of the energy of the positive half period will be admitted. For each successive half period a smaller amount of the positive energy and a larger amount of the negative energy will be admitted, until, when the amounts of positive and negative energy admitted are equal, the telephone diaphragm will receive no net impulse at all. The amount of negative energy admitted will gradually increase from this time on, until finally all the energy of the negative half periods will be admitted to the telephone circuit. In other words, the telephone diaphragm is subjected to recurrent forces of the beat frequency, which latter may be easily adjusted to the sound of maximum audibility by altering the speed of the tone wheel. The current in the tone wheel circuit is shown in Figure 19. Higher harmonics, which will be superposed on the fundamental frequency, will be of small amplitude because of the large inductance in circuit, and will not affect the clearness of the note in any way.

It is not necessary to run the tone wheel at approximately its synchronous speed. The same effects will be produced if we run it at near one-half, one-third, etc., of its synchronous speed, with the only difference that a smaller portion of the incoming energy is transformed. The apparatus is very compact and convenient when used as a wave meter, for when synchronism is attained all sound disappears, and the wave length can be readily calculated from the number of teeth in the wheel and the speed of rotation.

Since this apparatus does not add to the losses of the telephone circuit, its energy efficiency is high and it permits very sharp tuning. It may be coupled electrically, inductively or capacitively to either the primary or secondary of the receiver, the choice being determined by the amount of interference to be avoided.

This type of receiving apparatus makes it possible to use a musical note which can be read through static, and also frees us from interference to a very large extent. A very slight difference in the wave length sent from an interfering station will be sufficient to produce an entirely differently pitched sound in the telephones when the tone wheel is used. Thus the interfering station can be readily distinguished from the desired one. An alternative method of procedure in avoiding interference is to alter the speed of the tone wheel to a point at which it is in syn-

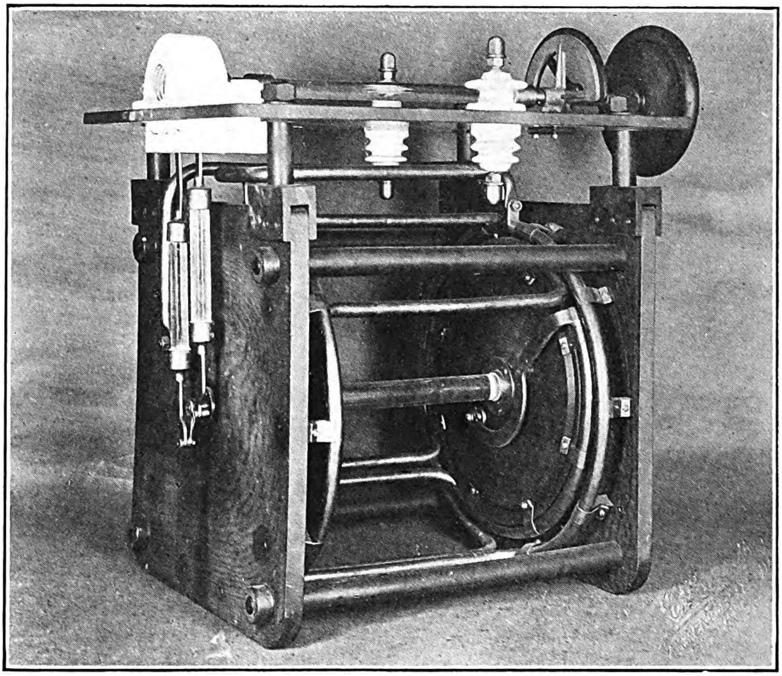


FIGURE 22—Antenna Variometer.

FIGURE 23—Receiving Room.

chronism with the undesired signals, which latter, as explained above, will then not be heard. The desired signals will however remain audible.

As an example of the application of this latter method, suppose we are receiving a wave length of 6,000 meters (corresponding to a frequency of 50,000 cycles). The tone wheel having 800 teeth will be at synchronous speed at 3,750 revolutions per minute. In order to get a high note in the telephones, we employ a slip of 1.5 per cent. thus running the wheel at 3,694 revo-

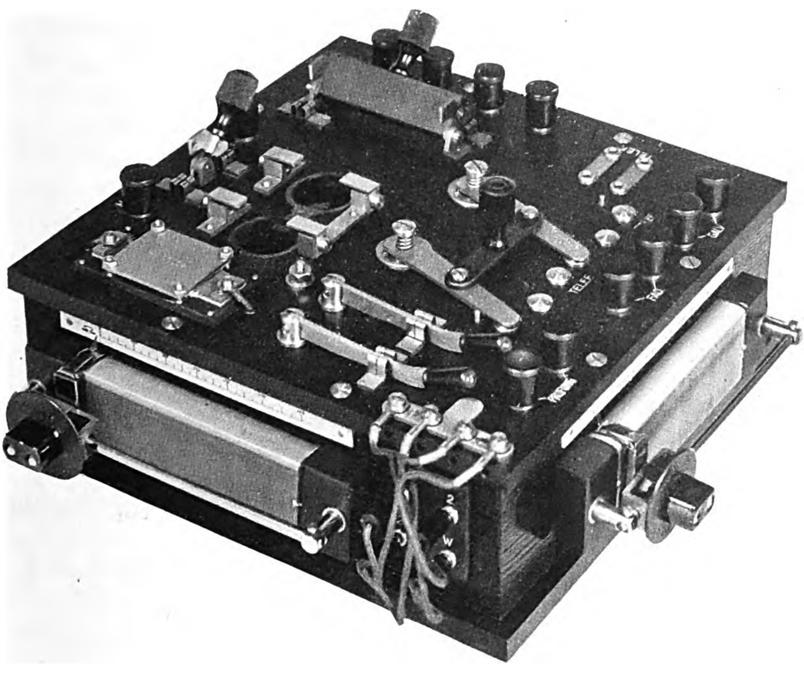


FIGURE 24—Receiving Set.

lutions. The note will therefore have a frequency of 750 cycles. Suppose that another radio station, working at a wave length of 6,100 meters should interfere. If the strength of the incoming signals in both cases is the same, it would be extremely difficult for operators using ordinary receiving sets to avoid this interference. They would be forced to use a very loose coupling, with the accompanying faint and doubtful signals. But with the tone wheel, there is no possibility of any interference at all. For the wave length of 6,100 meters, which corresponds to a frequency of 49,200, the synchronous speed of the tone wheel is 3,690. So

that the tone wheel, which is running at 3,694, is just slightly above synchronism for the incoming interfering signals, and will therefore produce a current in the telephones of frequency of 50 cycles (0.1 per cent slip). This latter tone is below the limit of audibility.

Using the devices described above, we have been able to telegraph from Eilvese to Tuckerton, a distance of nearly 4,000 miles (6,500 km.) beginning in July of last year. Since that time we have been in communication, and have transmitted messages at different times of day and night, except for a few weeks, when, because of a break down in the antenna, we were not able to transmit. We found the same difference between day and night transmission which has already been remarked by others.

While it is not so large with the long waves as with short waves, the difference is still considerable. There is also a large difference in the strength of the signals received on different days, which leads naturally to the idea that there are reflection and refraction effects which sometimes aid and sometimes hinder communication.

But it may be confidently said that, whatever the conditions, the problem of reliable commercial communication between our stations is practically solved.

## The Possibility of Radio Telephony.

In radio telephony, we find an interesting possibility of future development of the Goldschmidt system. Without discussing the question of the commercial value of radio telephony over long distances, I may say that we feel sure that the problem will meet an early solution. It is possible now to produce sufficient energy in an appropriate form. It is possible to control it, and it is very easy to receive it. A machine invented by Professor Goldschmidt, which, with very slight excitation, gives an extremely large output and so may be considered an amplifying or "trigger-control" generator, will certainly help to solve the problem. Its theory, together with some data obtained in tests, may be given in a future paper.

Tuckerton, New Jersey,
January 14, 1914.

## DISCUSSION.

**Robert H. Marriott:** Transoceanic means of communication in addition to the cables are certainly desirable, and the radio station described evidently was designed with a view to approaching as nearly as possible to cable utility. I presume duplication of parts is contemplated to insure continuous service.

The development of high power generators for radio frequency, equal amplitude alternating current has been spoken of for some time as the solution of the problem of long distance radio communication and this paper describes stations which are believed to be beyond anything which has been done in this line.

The radiation of high power in the form of equal amplitude waves, as is accomplished by this machine, may take the place of the ordinary method of sending groups of waves of decreasing amplitude, because the ordinary method insuring high powers where the station is located near the track of vessels may interfere with communication with ships. And ship communication is not to be interfered with because it is relied upon for the saving of life.

The tone wheel is an unexpected instrument in that it apparently provides an efficient detector and an interference preventer in one.

I believe you will all admit that these stations are an engineering proposition. What would have been said twenty years ago if a man had stated he could connect one end of a conductor to earth, hold the insulated end 800 feet in the air, put 100 K. W. in that conductor, and use that arrangement for telegraphing 4,000 miles? I have prepared a chart which, I believe, will illustrate that these stations are in a way very large things. As you will note from Figure 1, there is considerable land as well as water between Tuckerton, New Jersey, and Hanover, Germany. If we assume that Tuckerton sends equally well in all directions, its messages must travel over an area which includes, as seen by the large circle 2, Hanover (Germany), Spain, Peru, Nome (Alaska), and the North Pole. Furthermore, it is well known that the range of a radio station varies. In order that this station may compete with the cable its minimum range must not fall below 4,000 miles for any very great part of the time; which means it must reach much further under the best conditions. I have found by some hundreds of tests that shorter waves of rapidly decreasing amplitude, such as were used by vessels, give rise to a range variation somewhat as shown in the smaller circles in Figure 2. That is, the range of these small stations is about ten times as great at

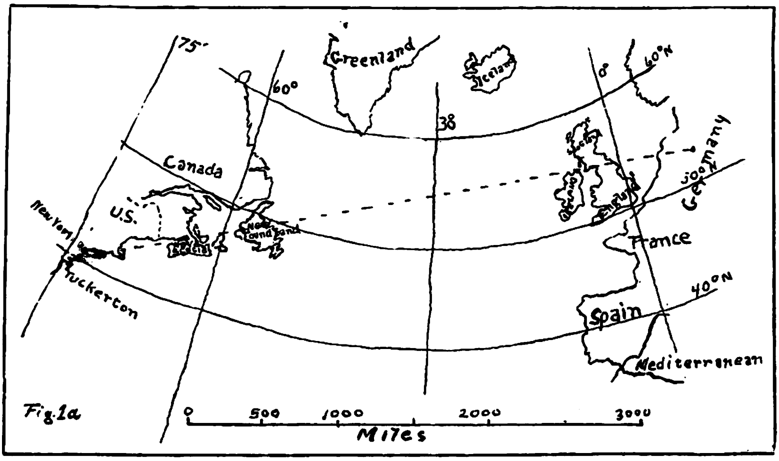



FIGURE 1.

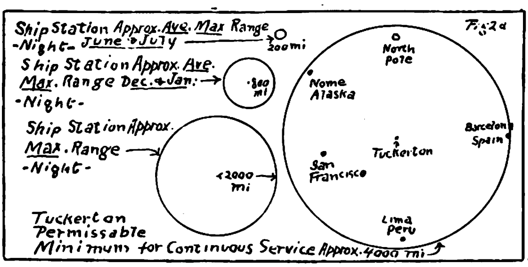



FIGURE 2.

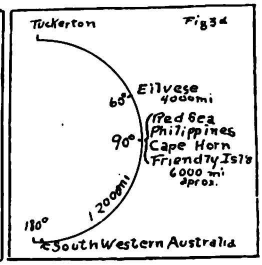



FIGURE 3.

night under the best winter conditions as it is under the average July day conditions. Ten times the normal Tuckerton range is 40,000 miles. If, on the basis of diminished variation with long equal amplitude waves and less total atmospheric variation over very long ranges, we discount this 40,000 mile range seventy per cent., we still have a possible range of 12,000 miles, which is half way around the earth. That is, Tuckerton under favorable conditions may be capable of transmitting as far as any station will transmit, so long as transmission is confined to this earth. Southwestern Australia is nearly opposite Tuckerton, and there are radio stations in that locality which possibly could be used with kites for such an experiment.

Time and news are now sent to many receiving stations in areas two thousand miles or more in diameter, and some of these receiving stations have cost but a few dollars. We may be very

near to a time when news will be sent from one or two stations to a great many inexpensive receiving stations scattered all over the world.

**E. F. W. Alexanderson:** The development of the Goldschmidt alternator represents a masterful application of the principles of alternating current design. The difficulties that must have been encountered can best be appreciated by those who have done work along similar lines. When, on the instigation of Prof. Fessenden I took up the development of a 100,000 cycle alternator on behalf of the company with which I am connected, the difficulties encountered seemed to be almost insuperable, and a number of models had to be discarded before a practical machine was produced. The Goldschmidt alternator works on an entirely different principle. It might be said that the Goldschmidt alternator is equivalent to such dynamo machines as the induction motor, where the active field is produced by the armature reaction of the winding itself; while the 100,000 cycle alternator, to which I referred, is equivalent to the salient pole alternator, the field being produced by the shape of the pole pieces and the armature reaction being incidental. In the 100,000 cycle alternator the winding pitch is only 1–16 of an inch (1.5 mm.), and it is, therefore, evident, that the armature reaction can play no considerable part in creating the active field. In the Goldschmidt machine, on the other hand, the winding pitch is 1 centimeter, as we have been told.

It is difficult to come to an understanding of the two working principles without comparing them on the basis of the same frequency. When a machine is designed for 50,000 cycles, the problem is in many ways easier. For instance, a 200,000 cycle alternator, which has been built, has so small a pole pitch that a special winding had to be devised with less than one slot per pole. If the same principle is applied to a 50,000 cycle machine we get a winding pitch of one-half centimeter, which is not so far from the dimensions of the Goldschmidt machine, and the same principle of reducing the number of slots can be carried still further. Thus we will deal with structures of substantially the same dimensions.

The difference is in the method by which the pulsation in the magnetic field is produced. One machine has a rotor made as a solid disk, designed for high speed, while the other must be operated at a lower speed because the rotor supports laminations and windings.

For those who are familiar with the parallel operation of ordinary alternators, it may be of interest to know that the machine

with which I am familiar can be synchronized, and operated in multiple, and it is worth noting that the constants which apply for parallel operation for ordinary machines apply to the same degree to a 100,000 cycle machine; in other words, the relation between reactance and resistance must be within certain limits, in order to insure stable operation. In connection with this subject I would ask whether it is possible to operate the Goldschmidt alternators in multiple. On general principles, it ought to be possible with any alternator, but with the rigid requirements of tuning in order to multiply the frequency, it is conceivable that these limitations would be outside the limitations of multiple operation.

I can confirm the statement in the paper that it is perfectly feasible to regulate the speed with sufficient accuracy for radio communication. In tests made with a receiver working on the Fessenden Heterodyne principle, by creating beats between two frequencies, it has been ascertained that the frequency can be kept so constant that no appreciable fluctuations are heard in the tone produced by the difference between the two frequencies.

I am much interested in what was said in the paper about the alternator for radio telephony. I demonstrated a number of years ago a trigger alternator for that purpose. It was built for 15,000 cycles and excited by telephone currents. In order to produce the necessary excitation, with as small an amount of energy as possible, a winding was used in which the same conductors served as a magnetizing winding and as an armature winding for the generated current. The results produced by this trigger alternator were very satisfactory. We obtained good articulation and large amplification, but another device was then developed which was more promising for this particular purpose. The object of this latter is to control the output of the radio frequency alternator in the same way as it might be controlled by regulation of the field strength. The controlling device is built like a transformer, with two magnetic circuits and two electrical circuits interlinked in such a way that there is no mutual induction between the two windings, but the exciting circuit controls the inductance of the radio frequency circuit by varying the iron core saturation. The current which can pass through the radio frequency coil is proportional to the exciting current. This device thus makes it possible to use an alternator with a solid field, and to get the same results as if it had a laminated field and were controlled by regulation of the field strength.

While it has proven possible to build radio frequency alternators of considerably higher frequency than the one described, and while

there is every reason to think that other machines can be built in equally large units, the accomplished fact that an alternator as large as the one described has been successfully completed has given an impetus to radio communication by the continuous wave system. For this, we must congratulate the inventor, for this invention will undoubtedly prove of benefit to all those who are working along similar lines.

**Lee de Forest:** The paper is particularly interesting to me, because for two years I was associated with the development of another method of producing continuous oscillations: the development of the Poulsen arc for radio frequencies; and I should like briefly to sum up what occurred to me as the points of distinction between the two methods and the parallel advantages and disadvantages.

In the Goldschmidt machine the disadvantages are high cost and the necessity for absolute constancy of speed (tho the latter problem has now been sufficiently solved), complication of circuits and the constructions involved by them, and especially the lack of flexibility for changes of wave length. You will realize that in long distance radio telegraphy it is very important, at times, to be able to change the wave length very suddenly, because of the "selective absorption" by reflection from the outer atmosphere. In California we found, using certain wave lengths, that the intensity of signals changed from, say, 40 times audibility to 2 or 3 times audibility, and this effect appeared sometimes within a period of four or five minutes, generally near twilight. At the same time the "compensation wave," the wave length of which varied from that of the first by not more than 5 per cent., did not decrease to any such extent. Sometimes it was found to be increased in intensity. At such times, therefore, it is important to change the wave frequency very quickly. Such a change in frequency with the Goldschmidt system of circuits can not be made very readily, I believe.

Naturally, an apparatus as beautifully built and as costly as this would require higher salaried operators than the much simpler arc apparatus. Then again, the key control is limited to one wave length. I mean that one cannot change the wave length with the key as is done with the Poulsen system, but that signaling is done by controlling either the output direct, or the field excitation (and simultaneously the excitation of the motor, so that there will be no change of speed).

With the Poulsen arc, the disadvantages are the necessity for

occasional changes of the carbon electrode, the attention which that requires on the part of the operator (who need be by no means exceptionally skillful), and the gas and water cooling supply. This latter, of course, is not a particular complication. The arc has probably a lower efficiency than the Goldschmidt alternator, altho in connection with that I will say that the efficiency of the large Poulsen generators has been increased from 20 per cent. to 60 per cent. during the last three years. This valuable work has been done entirely by American engineers.

Among the advantages of the Goldschmidt alternator are particularly the constancy of operation, for there should be no change whatever in the wave length or power output due to speed variation. This criticism, however, does not now apply to the larger Poulsen arcs, because the accidental changes in wave lengths are usually small and insufficient to interfere with the energy of the radiation. The larger power of the Goldschmidt alternator (at present 150 kilowatts in the antenna) has not yet been equalled at any Poulsen station. Sixty kilowatts in the antenna has been attained in the South San Francisco station. But one principal advantage of the Poulsen system is the utmost simplicity of the oscillating circuit, and that no condenser except that comprised by the antenna and earth is required. It is perfectly easy to change the wave length within reasonable limits instantly by simply throwing a switch. Ease of key control in the Poulsen system is a favorable factor. The key controls and short circuits a certain amount of inductance in the transmission antenna, and this permits both a sending wave and a "compensation wave," so that it is perfectly simple to transmit on either one at will merely by throwing a switch at the key itself. This double wave also adds to the secrecy of transmission. Amateurs, who are not equipped with refined apparatus for cutting out interference and tuning properly, especially on the long wave lengths, are generally baffled. This element of secrecy does not, of course, apply to stations equipped for reading either the Goldschmidt or the Federal stations. Both the Goldschmidt and Federal companies' systems represent great strides beyond all methods of transmission by sparks with slowly damped wave trains. But I do not think either of these systems is the last word in radio transmission. Apropos of the amounts of energy radiated, I would say that in Washington and in New York messages are now being received daily both from Hanover and from South San Francisco. The power at Hanover is 150 kilowatts in the antenna and at South San Francisco about 60 kilo-

watts, and I am credibly informed that the signals from South San Francisco are considerably stronger than those from Hanover. At night we get signals from an arc station at Honolulu using 25 kilowatts and practically 6,000 miles away (or a quarter of the earth's circumference) with surprising loudness.

**John Stone Stone:** Besides the very unusual and interesting dynamo described in this paper, the paper has considerable interest, as showing the extent of the very rapid evolution of the art of radio-telegraphy in two particulars:

1st. The increase in wave lengths used, and

2d. The gradual but rapid departure from the highly damped wave trains of the early open spark systems, first to the more persistent wave trains of the quenched spark system and finally to continuous or undamped wave trains.

I notice that the author regards both of these features as advantageous, but I am inclined to believe that so far as the enormous increase in wave length described in this paper is concerned, he is making a virtue of necessity, since the difficulty of constructing a dynamo to produce directly currents of more than 50,000 cycles at a capacity of 100 K. W. or more is at present evidently well-nigh insurmountable.

If the wave length used at the station described, with its gigantic antenna, had been that corresponding to the fundamental of the antenna, or approximately 1,500 meters, instead of 6,000 meters, the radiating capacity of the antenna for given antenna current would have been 16 times greater, and what is perhaps more important, the receiving or absorptive power of the antenna of distant receiving station would also have been increased 16 fold. Furthermore, this is but one of the numerous advantages that would follow from a decrease of the wave length. But to obtain a wave length of 1,500 meters would require a current having a frequency of 200,000 cycles.

On the other hand, there is no question of the great advantages which result in the use of continuous or undamped wave trains. There is not sufficient time now to enumerate these. I feel that the continuous wave train has come to stay, while I believe that the wave lengths developed at high power, long range stations must eventually be reduced to as near the fundamental or natural wave length of the antenna at such stations as is practicable.

If the continuous or undamped wave train is destined to completely supercede the damp wave trains, as I believe it is, this

does not mean that high frequency dynamos will nescessarily be used to supply the electrical energy at the frequency radiated. I say this for the reason that the antenna of the average radio station is incapable of radiating or absorbing any practically effective amount of energy per second at wave lengths of three thousand meters or more, while this is the shortest wave length that a dynamo of more than a small fraction of a K. W. capacity has been able to generate. Moreover, when we consider the enormous gyroscopic force of the rotor in either the Goldschmidt or the Alexanderson dynamo, we see that the use of such high frequency dynamos on board ship is out of the question, as either of these machines would tear itself to pieces, if operated at full speed on anything but a practically immovable foundation. In this connection it is to be remembered that a majority of the radio stations is to be found on board ships. Further, in this connection, ships' antenna systems are necessarily entirely too small to radiate or receive energy effectively at a frequency of the order developed by high frequency dynamos.

It seems as if in spite of the great skill and originality displayed by Goldschmidt, Alexanderson and others in designing high-frequency dynamos, we should, nevertheless, ultimately be forced to use the undamped oscillator of the general type first suggested by Elihu Thompson in 1892, or thereabouts. I understand that a modified form of such an oscillator with a capacity of 100 K. W. has been used with some success recently by the Federal Telegraph Company on the Pacific Coast in telegraphing from San Francisco to Honolulu and to ships on the Pacific Ocean. This oscillator is practically unlimited as to the frequency of the current it can generate.

**John Stone Stone** (by letter): The high frequency dynamo of this paper resembles a dynamo I designed some fourteen years ago, and differs from it chiefly in that my dynamo had no winding on the rotor. In fact my dynamo had but one winding, which served both as field and armature winding.

In its simplest form, illustrated in Figure 4, the machine develops, on open circuit, an e.m.f. comprising a fundamental *and all the odd* harmonics, but the instant you begin to draw a current corresponding to one of these *odd* harmonics, say of the frequency $n$, there immediately springs into existence in the e.m.f. of the machine, *all the even* harmonics of the fundamental, but chiefly, the even harmonics of the frequencies $n-1$ and $n+1$.

The elementary theory of this early machine of mine is very

simple, and because there is no winding on the rotor, there is a minimum of magnetic drag or transverse field, so that the elementary theory gives a much closer approximation to the actual behavior of the machine than could be expected of an elementary theory of the Goldschmidt dynamo. Nevertheless this elementary theory of my simpler machine does not differ materially from that of the Goldschmidt dynamo described by Mr. Mayer and sheds considerable light on the behavior of the Goldschmidt dynamo. For that reason I venture to touch upon it here.

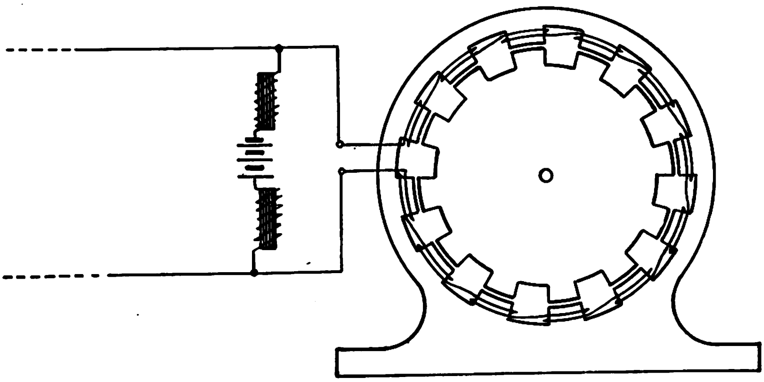


FIGURE 4.

The approximate value of the permeance per pole of the machine, as it varies with time, is given graphically by the zig-zag full line (1) of Figure 5, and analytically by the cosine series.

$$P = P_0 - P_1 \left(\cos \omega t + \frac{1}{3^2} \cos 3\,\omega t + \frac{1}{5^2} \cos 5\,\omega t \ldots\ldots\right)$$

in which $\frac{P_0}{P_1}$ is but slightly greater than unity.

If $I_0$ (full line 3 of Figure 5) be the constant unidirectional exciting current, the total excitation flux per pole will be

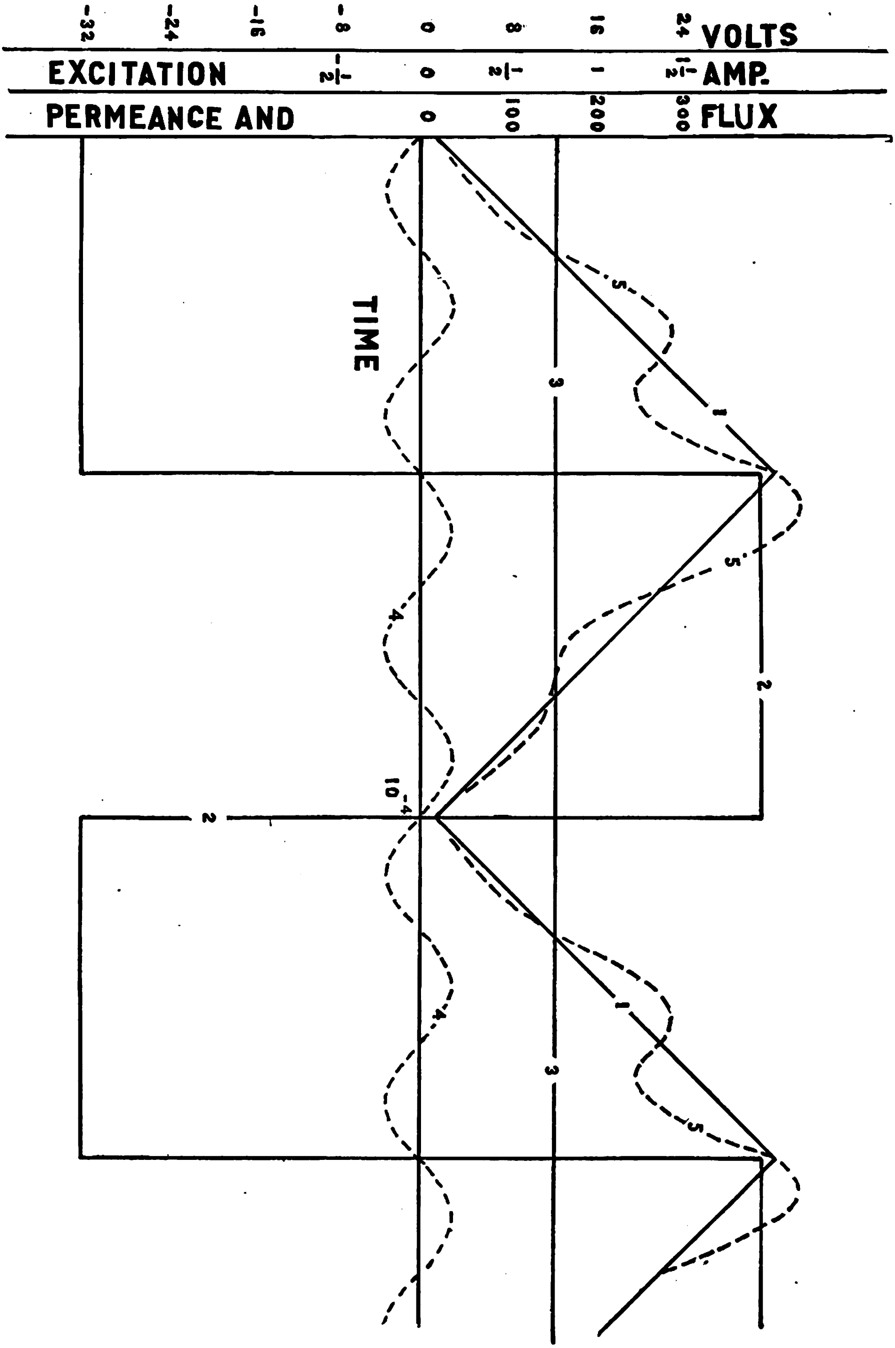
$$\phi_0 = \Phi_0 - \Phi_1 \left(\cos \omega t + \frac{1}{3^2} \cos 3\,\omega t + \frac{1}{5^2} \cos 5\,\omega t \ldots\ldots\right)$$

where $\Phi_0 = 4\pi N I_0 P_0$

and $\Phi_1 = 4\pi N I_0 P_1$

N being the number of turns of the winding per pole.

This flux $\phi_0$ may be represented graphically by the same zig-zag line (1) of Figure 5, if, as in the case of the particular



VOLTS
-32
-24
-16
-8
0
8
16
24
EXCITATION
AMP.
PERMEANCE AND
FLUX
100
200
300
TIME


FIGURE 5.

machine therein illustrated, the magnetomotive force of excitation per pole is unity.

The induced e.m.f of the machine on open circuit will be represented by the succession of rectangles of the full line (2) Figure 5, and analytically by the expression

$$e_0 = -E_0 \left(\sin \omega t + \tfrac{1}{3} \sin 3\,\omega t + \tfrac{1}{5} \sin 5\,\omega t \ldots\ldots\right)$$

But let us now see what happens when we draw off a current from this machine. Suppose we draw off a current of periodicity $5\omega$ and of that periodicity only. Further, for the sake of simplicity, suppose we so adjust matters that the current is in phase with the e.m.f. engendering it. Let us call this current—$I_5 \sin 5\,\omega t$, then the magnetomotive force per pole due to it will be —$F_5 \sin 5\omega t$ where $F_5 = 4\pi N I_5$. The flux per pole due to this current will be

$$\phi_5 = -F_5 P_0 \sin 5\,\omega t + \tfrac{1}{2} F_5 P_1 (0.04070 \sin 2\,\omega t + 0.9877 \sin 4\,\omega t + 0.9918 \sin 6\,\omega t + 0.1052 \sin 8\,\omega t + 0.0356 \sin 10\,\omega t \ldots\ldots)$$

This shows the importance of the *even* harmonics introduced by permitting a current to be developed of a frequency of one of the *odd* harmonics of the fundamental. We see that of the even harmonics only the components of periodicity $4\omega$ and $6\omega$ are of much importance. These even harmonics will give rise to voltages in the windings of the machine and the question immediately suggests itself, what will result from permitting a current to flow which has the frequency of one of these even harmonics? What will its effect be on the e.m.f. of periodicity $5\omega$? Will it help or will it hinder the machine in developing a current of periodicity $5\omega$? Let us draw a current—$I_4 \sin 4\,\omega t$. Then the flux per pole due to it will be

$$\phi_4 = -F_4 P_0 \sin 4\,\omega t + \tfrac{1}{2} F_4 P_1 (0.07111 \sin \omega t + 0.9796 \sin 3\,\omega t + 0.9876 \sin 5\,\omega t + 0.1028 \sin 7\,\omega t \ldots\ldots)$$

From this expression we see that, other things being equal, drawing off a current of periodicity $4\omega$ increases the e.m.f. of the machine at periodicity $5\omega$ and that in order to increase the output at periodicity $5\omega$ it is desirable to draw off a current at both periodicities $4\omega$ and $6\omega$.

Further consideration of the subject along the same lines shows that drawing off currents of frequency corresponding to the fundamental and to each of the harmonics, assists in the development of the e.m.f. of any one of the other harmonics.

A good deal that is of interest, in a quantitive way, can be dug out of such an elementary theory of these machines.

Of course on open circuit, even my machine shows slight even as well as pronounced odd harmonics in its E.M.F. These even harmonics are due to hysteresis and to eddy currents. Since each of those phenomena produces a lag in the change of flux of the rotor, they make the machine act exactly as if there were a winding on the rotor and small currents were being drawn from this second winding, one corresponding to each of the odd harmonics.

The resonant circuits used to draw off the component currents in the case of such machines should each have sufficient selectivity

$\sqrt{\frac{L_n}{C_n R_n^2}}$ to prevent the passage through it of any appreciable

amount of current of a frequency different from $n$, namely that which the circuit in question is designed to draw from the machine, but it should not *per se* be resonant to the frequency $n$, of the current it is designed to pass. It should have, for such a current, a negative reactance equal to the positive reactance of the winding of the machine for that frequency.

The values of the auxiliary inductances of these branch circuits do not affect the various components of the voltage of the machine in the same way as does the inductance due to the leakage flux of the machine and we may therefore safely conclude that they do not act as a simple loose coupling between the two circuits of the Goldschmidt dynamo to reduce the number and magnitude of the harmonics developed, as has been suggested by Professor Pupin. They exert no harmful effect. In this connection it is to be noted that there is a separate inductance coil and condenser in each tuned branch circuit.

In Figure 5, the dotted line 4 illustrates a current of periodicity $3\omega$ drawn from the machine, and the dotted line 5 illustrates the resulting modification of the flux when the amplitude of the current corresponding to the third harmonic is one-fourth the value of the excitation current (3) of Figure 5.

On the occasion of the presentation of Mr. Mayer's paper before the American Institute of Electrical Engineers and the Institute of Radio Engineers, Professor M. I. Pupin discussed the Goldschmidt alternator critically. He drew certain conclusions as to the maximum efficiency of such machines as limited by magnetic leakage between rotor and stator and the effective resistance of the machine. He further claimed priority in the

development of the theory of such machines. According to Professor Pupin, the tone wheel was analogous to the "heterodyne" receiver, being based on the beat principle, whereby thru the interaction of tones of inaudible frequencies a note of audible frequency is produced.

Because the stress of other duties prevented him from giving the necessary time to the revision of his discussion, Professor Pupin requested the Editor to withdraw it from publication. This has accordingly been done.

A portion of the answers by Professor Goldschmidt and Mr. Mayer are however published, for the technical information of the readers of the PROCEEDINGS.—(EDITOR'S NOTE.)

**Dr. Rudolph Goldschmidt** (by letter to Mr. Mayer): . . . I was very pleased to hear that so prominent a man as Professor Pupin has become interested in my invention, especially as he himself has studied the problem of the production of very high frequency energy by the reflection principle. Since he has stated that a great variety of higher harmonics are obtained in the circuits, I believe he has not applied the actual principle of my invention, which involves, as you know, the building up of the highest frequency energy by providing paths of minimum impedence for all the lower frequencies. This latter method is the only one which makes these machines practicable. I think you would do well to invite Professor Pupin to see the machine working at Tuckerton. I have no doubt that he will be convinced that not only is the principle correct but also that the machine works perfectly as a whole. It will further be evident to him that any amount of power can be obtained by simply increasing the dimensions, as with any ordinary dynamo.

At the same time Professor Pupin may satisfy himself that the method of reception of signals by means of the tone wheel is not at all related to the method of reception involving beats and tone production in the telephone receiver used in conjunction with a crystal rectifier. The tone wheel is an actual frequency transformer, which directly changes the radio frequency energy into audio frequency energy.

(Mr. Mayer has informed the Editor that an invitation to visit the Tuckerton station was sent Professor Pupin on May 27, 1914.)

**Mr. Emil Mayer** (by letter): I wish to express my regret that, because of the late hour at which the original discussion on

my paper terminated, it was not possible for me to answer the speakers on that occasion.

. . . It has been stated by Professor Pupin in connection with his claims to priority that higher harmonics are produced in a simple closed circuit rotating in a magnetic field. These harmonics are undoubtedly present, but this is far from being the principle of the Goldschmidt alternator. No doubt there are higher harmonics of all values produced when the field is not sinusoidal but of such space or time distribution that, when analyzed, these upper frequency components of the field would be discovered. But of all these frequencies, the Goldschmidt alternator uses *only the fundamental.* And if it were possible to produce by direct current excitation a field such that only this pure fundamental frequency were present in the first circuit, a Goldschmidt alternator of maximum efficiency would be obtained. The machine conceived by Professor Pupin must therefore be entirely different in nature from the Goldschmidt alternator.

As has already been pointed out in this paper, magnetic leakage is a serious factor in limiting the output of all radio frequency alternators. But it is in just this respect that we find one of the advantages of the Goldschmidt principle, for Goldschmidt is able to design his alternator for a much lower frequency than the one which is radiated. A smaller number of poles is therefore required, and accordingly a very much lower magnetic leakage is secured. As a matter of fact, the experimentally determined ratio of exciting direct current to final antenna current after a fourfold frequency transformation is one to one if the antenna resistance is not higher than 6 ohms. This shows that the magnetic leakage cannot be excessively large.

. . . It has been claimed by Professor Pupin that an exact theory shows that all the lower frequencies exist in their full strength. . . . This is not the case. On the contrary, the exact mathematical theory enables us to calculate in advance what must be the constants of the different circuits (inductance, resistance, and capacity), in order that the lower frequencies shall cancel absolutely. The very simplest experimenting with such alternators as these shows that the addition of any one of the higher frequency circuits markedly reduces the lower frequency currents, provided that correct tuning methods are employed. This same reduction applies, naturally, to the corresponding lower frequency magnetic fields, and consequently to their respective hysteresis and eddy current losses. . . . The extent to which these losses are reduced is perhaps best shown by the fact

that with 150 kilowatts input for the driving motor, an antenna current of 150 amperes is obtained while a rapid succession of dots and dashes were sent.

That the tone wheel depends on the beat principle may be positively denied. Beats are produced if two frequencies of nearly the same value are combined. In the case of the tone wheel, there is energy of only *one* frequency present, and this energy, by purely mechanical means, is changed into an audible form. There are no beats produced. . . .

In answer to Mr. Alexanderson's question as to the feasibility of running Goldschmidt alternators in parallel, it is possible to respond affirmatively. So long as the driving power is reasonably constant this can be done. In an alternator of this kind, the "synchronising force," that is, the available energy which corrects discrepancies from the "in phase" position of the moving parts of the machines when the driving power of one of the machines changes slightly, is comparatively low. The reason for this is that the rotating masses are very large in proportion to the output per pole.

I agree heartily with Mr. Alexanderson's statement that it is not difficult to keep the speed of these machines constant. The trigger control devices which Mr. Alexanderson described seem to me very ingenious, and I should be interested to learn more of them.

A few remarks may be added to Dr. de Forest's summary of the relative advantages and disadvantages of the Goldschmidt and Poulsen systems. He has overestimated the trouble required to keep the alternator speed constant and the amount of skill required on the part of the operator. All the operator has to do is press a key and watch the ammeter. These duties are no more difficult than removing arc electrodes, etc. Dr. de Forest has also overestimated the difficulty of changing wave lengths quickly. Using the Goldschmidt alternator, it is very easy to arrange matters so that such changes of wave length can be secured by merely throwing over a few switches and increasing or decreasing the speed of the machine. Naturally the adjustments must be properly made in advance, and not more than two or three given wave lengths will, in general, be available.

So far as over-all efficiency in operation is concerned, a great advantage of the Goldschmidt system is that in the interval between signals the full energy is not radiated unnecessarily. Control of the radiated energy is by means of the exciting current, which is made and broken, so that between signals the machine

is running at approximately no load. As to the comparative loudness of the signals received from San Francisco and from Hanover in Washington and New York, there may be some special reason for this effect applicable to these latter stations only. At Tuckerton, however, the signals from Hanover are very much louder than those from San Francisco.

As Mr. Stone has said regarding the best wave length for long-distance service, there is no doubt that for trans-Atlantic work there is a minimum absorption and a maximum efficiency of transmission at a wave length which is considerably higher than that naturally radiated by our antenna. Whether or not this most desirable wave length is above or below the one we are now using remains to be determined. Which ever, however, it will be readily possible by certain mechanical devices to work at the desired frequency with, perhaps, a slight diminution of over-all efficiency.

Since the date of the opening of the Tuckerton station, it has been successfully received at Eilvese with sufficient strength to permit the use of a photographic recorder (Einthoven thread galvanometer), according to information received by the Editor.—(EDITOR'S NOTE.)

VOLUME 2 JUNE, 1914 NUMBER 2

# PROCEEDINGS
of
# THE INSTITUTE OF RADIO ENGINEERS

(INCORPORATED)

OFFICERS, COMMITTEES, SUPPLEMENTARY LISTS OF MEMBERS AND ASSOCIATES OF THE INSTITUTE, AND GROWTH OF MEMBERSHIP CHART

THE EFFECT OF A PARALLEL CONDENSER IN THE RECEIVING ANTENNA
LOUIS W. AUSTIN

DIELECTRIC HYSTERESIS AT RADIO FREQUENCIES
E. F. W. ALEXANDERSON

SPECIFICATIONS FOR STEAMSHIP RADIO EQUIPMENT
ROBERT H. MARRIOTT

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.
and the Editing Committee
John L. Hogan, Jr., Chairman, Lloyd Espenchied, Arthur A. Hebert,
Louis W. Austin (ex-officio)

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# CONTENTS

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| Binyon, Basil, General Manager, Anglo-French Wireless Co., Hastings House, Norfolk St., Strand, London, England. | A<br>M | Sept. 9, 1914<br>Sept. 9, 1914 |
| Cole, William Beale, Engineer, Marconi's Wireless Telegraph Co., Marconi House, Strand, London, England. | A<br>M | July 1, 1914<br>Oct. 14, 1914 |
| DeForest, Lee, *Ph. D.*, (*Past President, S. W. T. E.*), Inventor and Scientific Director, DeForest Radio Telephone and Telegraph Co., 1391 Sedgewick Ave., New York; res., Spuyten Duyvil, N. Y.* | A<br><br>M | Charter Member, S.W.T.E.<br>Oct. 14, 1914 |
| Ditcham, William Theodore, Chief Engineer, Grindell Matthews Wireless Telegraph Synd., Twickenham, England; res., "Kildary," Lebanon Park, Twickenham, England.* | A<br>M | June 3, 1914<br>June 3, 1914 |
| Goldschmidt, Rudolph, *Ph. D.*, *Prof. Dr.*, Radio Engineer and Inventor, Reichskanzler Platz 3, Charlottenburg, Berlin, Germany. | A<br>M | Sept. 9, 1914<br>Sept. 9, 1914 |
| Hewitt, Peter Cooper, Inventor and Scientist, Madison Square Garden Tower, 26th St., New York. | A<br>M | June 17, 1914<br>June 17, 1914 |
| Keith, Hilton, Construction Engineer, Marconi's Wireless Telegraph Co., care Poldhu Marconi Station, Mullion, S. Cornwall, England;* res., 17 Newton Road, Bayswater, W., London, England. | A<br>M | July 16, 1913<br>Oct. 14, 1914 |
| Mauborgne, Joseph O., 1*st Lieut.*, *U. S. A.* In Charge of Radio Construction Work, Signal Corps, Ft. Mills, Manila, P. I. | A<br>M | July 1, 1914<br>July 1, 1914 |
| Meissner, Alexander, *Ph. D.*, *Dr. Ing.*, Chief Engineer of the Telefunken Laboratory, Gesellschaft für Drahtlose Telegraphie, Berlin; res., Tempelhofer Ufer, 25, Berlin, S. W., Germany.* | A<br>M | Aug. 12, 1914<br>Aug. 12, 1914 |
| Norman, *Sir* Henry, *M.P.*, Vice-President, Wireless Society of London; res., Honeyhanger, Haslemere, Surrey, England. | A<br>M | Aug. 12, 1914<br>Aug. 12, 1914 |
| Rein, Hanz, Chief of Laboratory, C. Lorenz A.-G.; res., Goettestr. IF, Portal II, Berlin, Germany. | A<br>M | July 8, 1914<br>July 8, 1914 |
| Sörenson, Aage S. M., Research Engineer, Goldschmidt Hoch Frequenz Maschinen Gesell., Marien Str. 12, Lichterfelde, Berlin, Germany. | A<br>M | Sept. 9, 1914<br>Sept. 9, 1914 |
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| FLOTTMAN, JOHN M., Wireless Operator, Marconi Wireless Telegraph Co., P. O. Box 80, San Francisco, Cal.;* res., Washington, Mo. | Aug. 26, 1914 |
| FORD, WALTER B., Electrician, Son Electric Co.; res., 3653 Arnold St., San Diego, Cal. | July 8, 1914 |
| FULLER, ERLE H., 1st Class Sergeant, Company E., Signal Corps, U. S. A., Ft. Shafter, Territory Hawaii. | Aug. 12, 1914 |
| GASKEY, SIGMUND, Radio Operator, Marconi Wireless Telegraph Co., Merchants' Exchange Bldg., San Francisco, Cal.;* res., 73 E. 30th St., Bayonne, N. J. | Sept. 9, 1914 |
| GOODWIN, AUBREY R., Experimenter, Wm. J. Murdock Co., res., 35 Pine St., Greenwood, Mass. | Oct. 14, 1914 |
| GOVERN, HARRY E., Assistant Sales Manager, H. Lee Mallory Co.; res., 251A Grand Ave., Brooklyn, N. Y. | Aug. 12, 1914 |
| GRAF, EDWARD, Radio Operator, Marconi Wireless Telegraph, Co.; res., 165 Sheridan Ave., Paterson, N. J. | July 1, 1914 |

* Denotes mailing address.

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| Graveley, Eugene C., Wireless Operator, Tropical Radio Telegraph Co., New Orleans, La.; res., 1302 Marengo St., New Orleans, La.* | July 1, 1914 |
| Gray, C. Louis, Clerk, Mechanics and Metals National Bank, New York; res., 3 Morgan Ave., Norwalk, Conn.* | July 1, 1914 |
| Grigg, Arthur, Private Branch Exchange Inspector, Cincinnati & Suburban Bell Telephone Co., Cincinnati, Ohio; res., 1548 Dudley St., Cincinnati, Ohio.* | June 3, 1914 |
| Grinnell, Milton Wilder, Radio Operator, Marconi Wireless Telegraph Co., Salem, Mass.; res., 29 Upham St., Salem, Mass.* | June 3, 1914 |
| Haines, Howard J., Law Student, Merchants' Claim Association, New York; res., 415 W. 22nd St., New York.* | July 1, 1914 |
| Haines, Kenneth B., Student, Yale University, New Haven, Conn.; res., 20 E. 45th St., New York.* | Aug. 26, 1914 |
| Haley, James A., Superintendent, Geo. A. Fuller Co.; res., 7 Saranac St., Dorchester, Mass. | Aug. 12, 1914 |
| Hantzsch, Ralph E., Radio Experimenter, 1161 Island Ave., Milwaukee, Wis. | July 1, 1914 |
| Hardy, Wilbur Hopkins, 778 Hale St., Beverly Farms, Mass. | June 3, 1914 |
| Hargett, Geo. C., Photographer, 1446 E. 86th St., Cleveland, Ohio. | Aug. 12, 1914 |
| Harris, William J., Radio Operator, Marconi Wireless Telegraph Co.; res., 532 No. 64th St., Philadelphia, Pa. | July 8, 1914 |
| Hayden, Thomas J., Instructor in Practical and Applied Electricity, Department of Education, City of New York; res., 783 St. Nicholas Ave., New York.* | July 1, 1914 |
| Hayes, H. D., Director of the School of Radio Telegraphy, Y. M. C. A., Los Angeles, Cal.;* res., 1130 W. 7th St., Los Angeles, Cal. | Aug. 12, 1914 |
| Heffernan, William J., Clerk, Chas. William Stores, res., 46 Strong Pl., Brooklyn, N. Y.* | June 3, 1914 |
| Higgs, Harry Y., Instructor in Radio Telegraphy, Brooklyn Telegraph School; res., 30 Irving Pl., Brooklyn, N. Y.* | Oct. 14, 1914 |
| Hill, Laurence D., Engineer, Marconi's Wireless Telegraph Co., Marconi Station, Clifden, Ireland. | Sept. 30, 1914 |
| Hiller, Herbert A., Chief Clerk and Secretary, Civil Service Board, U. S. Post Office, New York; res., 117 Hanover St., Silver Creek, N. Y.* | June 3, 1914 |
| Hilson, Edward, Radio Operator, American Hawaiian Steamship Co., 406 S. Broadway, Los Angeles, Cal. | Aug. 26, 1914 |
| Hogg, William Stetson, Jr., *U. S. N.* Radio Officer, U. S. S. "West Virginia," Pacific Station, via San Francisco, Cal. | June 17, 1914 |
| Horn, Charles W., Radio Operator, Tropical Radio Telegraph Co., New Orleans, La.;* res., Sagamore Hotel, Far Rockaway, L. I., N. Y. | June 3, 1914 |
| Howard, William H., Laboratory Assistant, Marconi Wireless Telegraph Co.; res., 1192 Broad St., Newark, N. J. | Aug. 12, 1914 |
| Howell, W. J., Radio Experimenter; res., 135 Edgecombe Ave., New York. | July 1, 1914 |

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| **Hubbard**, Geo. S., Construction Engineer, Marconi Wireless Telegraph Co., 50 Main St., San Francisco, Cal. | July 8, 1914 |
| **Hunter**, Herbert A., Radio Electrician, U. S. Naval Radio Station, Radio, Va.;* res., 90 Terrace Ave., Winthrop Beach, Mass. | Sept. 9, 1914 |
| **Johnson**, Geo. H., Electrical Helper to A. M. Jones, Berkeley, Cal; res., 6205 E. 14th St., Oakland, Cal.* | July 1, 1914 |
| **Keep**, H. Sanford, *Ensign, U. S. N.*, U. S. S. "Jenkins," care Postmaster, New York. | June 3, 1914 |
| **Kirsner**, Harry, Sergeant, C. A. C., Electrician in charge, Fort Andrews, Mass. | July 1, 1914 |
| **Kitchin**, Howard W., Chief Radio Electrician, U.S. Naval Radio Laboratory, Bureau of Standards, Washington, D. C. | Aug. 12, 1914 |
| **Knight**, Maurice E., Machinist, American Voting Machine Co.; res., 3 Edwin St.; Dorchester, Mass. | July 8, 1914 |
| **Knowles**, Edward P., Jr., Telegraph Operator, Penna. R. R.; res., 648 Princeton Ave., Trenton, N. J. | Aug. 12, 1914 |
| **Koehler**, Harry F., Operator, Marconi Wireless Telegraph Co.; res., Perkasie, Pa. | July 1, 1914 |
| **Krows**, Ralph, Manager, Ralph Krows Electric Co.; Seattle, Wash.; res., 2222 Emmons Pl., Seattle, Wash.* | Aug. 12, 1914 |
| **Kumeilike**, Lorenz Lei, Draughtsman, Federal Telegraph Co., 1004 Merchants' Exchange Building, San Francisco, Cal.;* res., 3017 Lee St., Berkeley, Cal. | Aug. 26, 1914 |
| **Laager**, Creston F. H., Draftsman, Standard Roller Bearing Co.; res., 1029 Belmont Ave., West Philadelphia, Pa. | July 1, 1914 |
| **Lachman**, Theo., Operator and Radio Electrician, U.S. Naval Radio Station, Beaufort, N. C. | Aug. 12, 1914 |
| **Lange**, J. Robert, Radio Operator, Marconi Wireless Telegraph Co.; res., 1938 Lemmon St., Baltimore, Md. | July 8, 1914 |
| **Lee**, Samuel E., Chief Electrician (Radio), U.S. Flagship "Wyoming," care Postmaster, New York;* res., Key West, Fla. | Aug. 26, 1914 |
| **Lehde**, Pendleton E., Wireless Testing Engineer, Vaccaro Bros. Steamship and R. R. Co.; res., 2223 Magazine St., New Orleans, La. | Oct. 14, 1914 |
| **Lemon**, Lee, Superintendent, Marconi Telegraph-Cable Co., 42 Broad St., New York;* res., 80 Prospect St., East Orange, N. J. | Sept. 9, 1914 |
| **Levinson**, Nathan, Shift Engineer, Marconi Wireless Telegraph Co., Kahuku, Oahu, T. H. | Aug. 12, 1914 |
| **Lindh**, Charles, Radio Operator, Mutual Telephone Co., Kaunakakai, Molokai, T. H. | Aug. 26, 1914 |
| **Lohmann**, John Andrew, Plate Printer, Harry Wiltshire; res., 213 West 120th St., New York. | July 1, 1914 |
| **Long**, Harvey H., Radio Operator, Marconi Wireless Telegraph Co., San Francisco, Cal. | Aug. 12, 1914 |
| **Lovejoy**, Edwin W., Operator, Federal Telegraph Co.; res., 1818 Magnolia, Los Angeles, Cal. | July 8, 1914 |

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| LYNCH, ARTHUR H., Radio Operator, Marconi Wireless Telegraph Co.; res., 118 St. James Pl., Brooklyn, N. Y. | Sept. 30, 1914 |
| LYON, HARRY H., Student, McKinley High School; res., Hyatsville, Md. | June 3, 1914 |
| MACKENZIE, ROY G., Radio Operator, Boston, Station, Marconi Wireless Telegraph Co.; res., 102 High St. Danvers, Mass.* | July 1, 1914 |
| MAHER, EDWARD T., Student; res., 3409 Grove St., Oakland, Cal. | July 8, 1914 |
| MANLEY, LEE L., Radio Electrician, Marconi Wireless Telegraph Co.; res., 788 Park Pl., Brooklyn, N. Y. | July 1, 1914 |
| MARSHALL, LEONARD H., Radio Operator, Marconi Wireless Telegraph Co.; res., 240 Westchester Ave., Port Chester, N. Y. | Aug. 12, 1914 |
| MARQUIS, A. N., JR., Westinghouse Electric Co., (Repair Shop); res., 618 Spring St., Seattle, Wash. | Aug. 26, 1914 |
| MAYER, ARTHUR W., Radio Operator, Marconi Wireless Telegraph Co.; res., 7 Chestnut Sq., Jamaica Plain, Mass. | July 8, 1914 |
| McCAY, DANIEL, Student, Cornell University, 6 South Ave., Ithaca, N. Y.;* res., 45 Lee Ave., Yonkers, N.Y. | July 1, 1914 |
| McCREARY, ARTHUR R., McCreary Moore Co., 508 Hall St., Kansas City, Mo.;* res., 1407 East 35th St., Kansas City, Mo. | June 17, 1914 |
| McGALL, PHILIP K., Radio Experimenter, 341 Gregory Ave., West Orange, N. J. | Oct. 14, 1914 |
| McLELLAN, ARCHIBALD, Engineer, Marconi's Wireless Telegraph Co., care Marconi Trans-Atlantic Station, New Brunswick, N. J. | Oct. 14, 1914 |
| MEYERS, EDWARD A., Telegraph Operator, Postal Telegraph-Cable Co.; res., 2079 Market St., San Francisco, Cal. | Aug. 12, 1914 |
| MONCEAU, JEAN, Navigating Officer, Royal Dutch West India Mail, S.S. "Commerwyne," Amsterdam, Holland. | July 8, 1914 |
| MOORE, ROBERT R., Secretary, Groves Bros. R. E. and Mtg. Co., Kansas City, Mo.; res., 200 East Armour Blvd., Kansas City, Mo.* | July 1, 1914 |
| MORAN, LEON STEELE, Electrical Engineer, Testing Dept., Electric Cable Co.; res., 224 Washington Ave., Bridgeport, Conn. | July 8, 1914 |
| MORSE, GUY E., Operator, Electric Park Radio Station; res., 4238 Harrison St., Kansas City, Mo. | July 8, 1914 |
| MOYER, SAMUEL G., Clerk, Bureau of Navigation, Dept. of Commerce, Washington, D. C.; res., The Savoy, Washington, D. C.* | July 1, 1914 |
| MUIR, JAMES B., JR., Student, University of California; res., 539 38th St., Oakland, Cal. | Oct. 14, 1914 |
| NALLY, EDWARD J., Vice-President and General Manager, Marconi Wireless Telegraph Co., 233 Broadway, New York;* res., Ossining, N. Y. | July 1, 1914 |
| NELSON, FRANCIS A., Operator, Marconi Wireless Telegraph Co., Miami Beach, Fla. | Aug. 26, 1914 |

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| NICHOLLS, GEO. WM., Assistant to Manager, Boston Division, Marconi Wireless Telegraph Co.; res., 889 Salem St., Maplewood, Mass. | June 3, 1914 |
| NICHOLSON, KNOX W., Student, Associated with Supreme Court, res., 1534 Spring St., Berkeley, Cal. | June 3, 1914 |
| O'NIEL, DONALD H. C., Junior Member, Robert O'Niel Piano Co., St. Louis, Mo.; res., 5740 Bartmer Ave., St. Louis, Mo.* | June 17, 1914 |
| OTT, GEO. A., Radio Electrician, U.S. Revenue Cutter "Pamlico," Newbern, N. C. | Aug. 12, 1914 |
| PAINE, ROGER W., *Ensign, U. S. N.*, U. S. S. "Patterson," care Postmaster, New York. | July 1, 1914 |
| PEARSON, HERBERT B., Hardwood Importer; res., 997 Sterling Pl., Brooklyn, N. Y. | July 1, 1914 |
| PEDERSEN, MARTIN P., Radio Engineer, Poulsen System; res., Rorholmsgade 22", Copenhagen Denmark. | Oct. 14, 1914 |
| PEMBER, HAROLD N., Student, Hartford Public High School; res., 2 Cone St., Hartford, Conn. | Aug. 12, 1914 |
| PENNYPACKER, THOMAS R., Student, Harvard University; res., 52 Mt. Auburn St., Cambridge, Mass.* | July 1, 1914 |
| PETERS, JOHN W., Patent Attorney, 52 William St., New York;* res., Roslyn, L. I., N. Y. | Aug. 12, 1914 |
| PICKEN, WILLIAM J., Engineer, Marconi's Wireless Telegraph Co., Ltd., care Marconi Trans-Atlantic Station, New Brunswick, N. J. | Sept. 30, 1914 |
| PILLSBURY, EDWARD BUTLER, Assistant Traffic Manager, Marconi Wireless Telegraph Co.; res., 313 East 21st St., Brooklyn, N. Y.* | July 1, 1914 |
| POHL, J. A., Port Manager, Marconi Wireless Telegraph Co., Marconi Station, Port Arthur, Tex. | July 1, 1914 |
| PORTER, RALPH H., Bookkeeper, Merchants' National Bank, Salem, Mass.; res., 7 Randall St., Salem, Mass.* | Sept. 9, 1914 |
| POTTS, JEROME, Radio Operator, Tropical Radio Telegraph Co., 17 Battery Pl., New York;* res., 148 Clinton Ave., Brooklyn, N. Y. | Aug. 12, 1914 |
| POWERS, WALTER PALMER, Conducting Electrical Research, University of Pittsburgh, Pittsburgh, Pa.;* res., 234 Craig St., Pittsburgh, Pa. | Aug. 12, 1914 |
| POWNALL, RAYMOND M., Radio Operator, Tropical Radio Telegraph Co., 321 St. Charles St., New Orleans, La. | Aug. 12, 1914 |
| PRENTISS, JOSEPH A., Civil Engineer, Richardson & Hale, care Mr. H. J. Power, 18 Clinton St., Everett, Mass.;* res., 206 Prospect St., Belmont, Mass. | Sept. 30, 1914 |
| PRESTON, JOHN ERNEST, Auditing Dept., Marconi Wireless Telegraph Co.; res., 859 Fulton St., Brooklyn, N. Y. | July 1, 1914 |
| PUMPHREY, WALTER H., U. S. Attorney, Dept. of Justice, Washington, D. C.; res., 1425 Belmont St., Washington, D. C.* | Aug. 12, 1914 |
| PURSSELL, CLARENCE V., Carpenter and Electrician; res., 1257 Morton St., Dorchester, Mass. | June 3, 1914 |
| RAWSON, H. E., Manager, Rawson Ranches, Kuna, Idaho. | July 1, 1914 |
| RECKSIEK, WM. H., JR., Radio Operator, U. S. S. "Minnesota," care Postmaster, New York;* res., 1222 C. St., S. W., Washington, D. C. | Aug. 12, 1914 |

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| REDFERN, O. R., Chief Operator and Inspector, Great Lakes Division, Marconi Wireless Telegraph Co.; res., 10th St. and 9th Ave., W., Duluth, Minn.* | July 8, 1914 |
| RICHARDSON, KENNETH, Radio Operator, Marconi Wireless Telegraph Co.; res., Box 686, Erie, Pa. | Sept. 30, 1914 |
| RICHMOND, H. B., Statistics Dept., Stone & Webster; res., 12 George St., Medford, Mass. | July 1, 1914 |
| RIES, ELIAS E., Electrical and Mechanical Engineer and Inventor, 116 Nassau St., New York. | Aug. 12, 1914 |
| ROBISON, SAMUEL S., *Capt., U. S. N.*, Assistant Chief of the Bureau of Steam Engineering, Navy Dept., Washington, D. C. | Oct. 14, 1914 |
| RODMAN, HAROLD LEE, Chief Operator, Trans-Pacific Plant, Heeia, Federal Telegraph Co.; res., Heeia, Cahu, T. H. (via Honolulu). | Sept. 30, 1914 |
| ROGATSKY, CARL H., Radio Experimenter; res., 526 86th St., San Diego, Cal. | Sept. 30, 1914 |
| RORKE, ELMO, Radio Instructor, Coast Artillery School, Fort Monroe, Va. | June 3, 1914 |
| SABIN, GLENN C., Electrician, Western Union Telegraph Co., Northampton, Mass.; res., 143 North St., Northampton, Mass.* | July 1, 1914 |
| SALZGEBER, JOHN W., Clerk, Comstock Cheney & Co.; res., Ivoryton, Conn., Box 126. | Aug. 26, 1914 |
| SCHELL, JOHN E., Chief Radio Electrician, Navy Yard, N. Y.; res., 190 Carlton Ave., Brooklyn, N. Y.* | July 1, 1914 |
| SCHMIDT, LAWRENCE R., Operator, Marconi Wireless Telegraph Co.; res., 234 West 111th St., New York. | Aug. 12, 1914 |
| SCHRAM, JACK, JR., Stationery Clerk, Tiffany & Co.; res., 21 Locust St., Brooklyn, N. Y.* | June 3, 1914 |
| SEELEY, ARTHUR PLATT, Switchboard Engineer, The Southern New England Telephone Co.; res., 55 Pearl St., New Haven Conn. | July 1, 1914 |
| SHERMAN, GEORGE C., Treasurer, St. Regis Paper Co.; res., 172 Ten Eyck St., Watertown, N. Y. | Aug. 12, 1914 |
| SHORT, HERBERT M., Chief Inspector, Marconi International Marine Communication Co., Ltd., 29 Cliff St., New York.;* res., 1164 44th St., Brooklyn, N. Y. | Sept. 9, 1914 |
| SKOVMAND, OTTO, Engineer, Poulsen System; res., Christianiagade 10, Copenhagen, Denmark. | Oct. 14, 1914 |
| SLAUGHTER, NUGENT H., Engineer in Charge, High-Power Station, Marconi Wireless Telegraph Co., Honolulu, T. H. | Aug. 12, 1914 |
| SMITH, HARRIS F., Engineer, U. S. Lighthouse Service, Portsmouth, R. I. | Sept. 30, 1914 |
| SMITH, VERNE E., Electrician, Knox Amusement Co.; res., Box 444, Knox, Pa. | July 1, 1914 |
| SPICER, EARL EUGENE, Electrician and Radio Operator, U. S. Revenue Cutter Service; res., 913 8th Ave., Seattle, Wash. | Aug. 26, 1914 |
| SPRAGUE, CLARENCE A., Assistant Examiner, U. S. Patent Office, Washington, D. C. | Sept. 30, 1914 |
| STETSON, DONALD T., Electrical Engineering Student, Minnesota State University; res., 2162 Carroll Ave., St. Paul, Minn. | Sept. 30, 1914 |

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## SUMMARY OF MEMBERSHIP

October 15, 1914.

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| MEMBERS | 93 |
| ASSOCIATES | 523 |
| Total | 616 |

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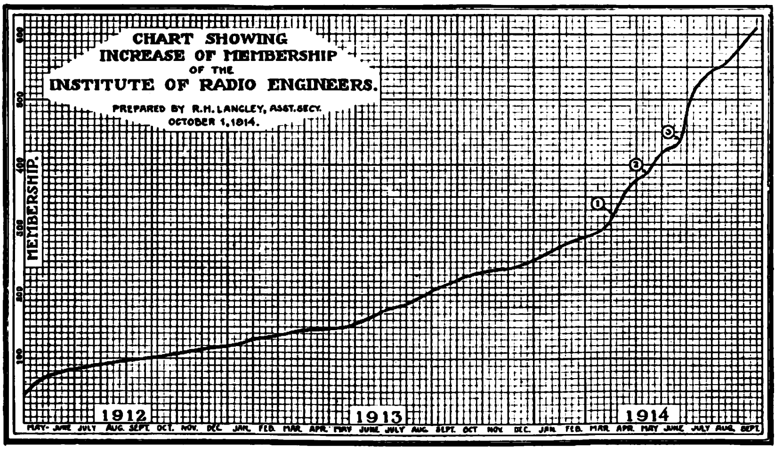
THE SECRETARY, INSTITUTE OF RADIO ENGINEERS,

71 Broadway, New York.




Thru the kindness of Mr. Ralph H. Langley, Assistant Secretary of the Institute, the Editor is enabled to present to the membership the above chart. This interesting curve shows the increase in membership of the Institute of Radio Engineers between May, 1912 and September, 1914. Since the preparation of this chart there has been a further considerable increase in membership. Attent'on is called to the accelerated rate of increase in membership directly above each of the points 1, 2, and 3 of the chart. At each of the points indicated by these figures, systematic efforts to increase the membership were made by the Board of Direction. The results were gratifying, and lead the Board to expect still greater increases in membership so soon as the advantages of participation in the Institute activities become even better known to the radio fraternity.

# THE EFFECT OF A PARALLEL CONDENSER IN THE RECEIVING ANTENNA.*

By

Louis W. Austin.

*President of the Institute.*

It is a common practice to make use of a variable condenser in parallel with all or a portion of the inductance of the receiving antenna, for the purpose of increasing the wave length to which the antenna is tuned. This method is very convenient, inasmuch as it does away with the necessity of small inductance steps, and also reduces the total amount of inductance required. It was believed at one time that it was possible in this way to increase the amount of energy delivered to the detector circuit above that obtainable by pure inductive tuning.

The comparison of receiving sets in which the parallel condenser is used, with those using inductive tuning, generally showed that the former were inferior to the latter in efficiency. For this reason an examination was made of the effect of replacing inductance by various amounts of parallel capacity.

The apparatus used consisted of an artificial antenna circuit containing a capacity representing the antenna, the receiving set under test, a resistance of 6 ohms to represent the antenna resistance, and a small coil to which was loosely coupled a buzzer driven wave meter adjusted to the wave length and sending decrement desired. The receiving set, which was originally designed for pure inductive tuning, was provided with a tuned secondary circuit consisting of variable inductance and variable capacity, with the iron pyrites detector connected in parallel to the capacity in the usual way. For the purpose of making quantitative comparisons the telephones were replaced by a sensitive D'Arsonval galvanometer of 2,000 ohms resistance.

The deflection was first measured using pure inductive tuning, the coupling being carefully adjusted to give the maximum

*Presented before the Institute of Radio Engineers, New York, March 4, 1914.

galvanometer deflection. A variable air condenser was then placed in parallel with the primary of the receiving set, and observations taken on various combinations of inductance and parallel capacity, the coupling between primary and secondary being adjusted in each case to give the maximum possible deflection.

Two such series of observations are shown in Tables I and II. Table I represents an antenna of small capacity, 0.0007 microfarad; while in Table II the antenna is considerably larger, and of 0.002 microfarad capacity. The tables show clearly the decrease in receiving efficiency when inductance is replaced by the parallel condenser. As is to be expected, more capacity can be used in the case of the larger antenna without materially decreasing the intensity of the received signals. In both cases, replacing half of the inductance by capacity reduces the deflection by approximately one third.

A number of other sets of observations were made, in some of which the artificial antenna was excited by sustained oscillations, and in some of which real antennae were used instead of artificial. In all cases, however, the influence of the parallel capacity was substantially the same as in the cases here given.

**SUMMARY:** Tuning inductances placed in artificial and actual antennae are shunted by a tuning condenser. In all cases the introduction of this capacity is found to reduce the strength of received signals.

## TABLE I.

Antenna Capacity = 0.0007 microfarad

$\lambda$ = 2000 m. $\delta_1$ = 0.10

| Parallel Capacity microfarad | Antenna Inductance microhenrys | Deflection mm. |
|---|---|---|
| 0 | 1330 | 230 |
| 0.00016 | 1180 | 210 |
| .00032 | 1050 | 195 |
| .00064 | 840 | 180 |
| .00100 | 820 | 160 |
| .00132 | 610 | 140 |
| .00165 | 540 | 125 |
| .00200 | 480 | 105 |

## TABLE II.

Antenna Capacity = 0.002 microfarad

$\lambda$ = 3000 m. $\delta_1$ = 0.10

| Parallel Capacity microfarad | Antenna Inductance microhenrys | Deflection mm. |
|---|---|---|
| 0 | 1100 | 110 |
| 0.00034 | 980 | 105 |
| .00073 | 874 | 95 |
| .00094 | 830 | 92 |
| .00147 | 720 | 90 |
| .00224 | 620 | 74 |
| .00314 | 515 | 56 |
| .00422 | 415 | 42 |

## DISCUSSION.

John Stone Stone: This paper discusses not only an interesting, but essentially a practical question.

In a very large number of instances the decrement $\delta_1$, of the wave trains to be received is less than $\delta_2$, that of the receiving aerial circuit when tuned by an auxiliary inductance or aerial loading coil to receive them. In such cases, there can be no doubt that the substitution of a condenser in parallel to the primary of the receiving transformer for the auxiliary aerial tuning inductance in series therewith, would diminish the rate of energy reception at the detector in the secondary circuit. In such a case the substitution of the parallel capacity for the series inductance would serve to increase the disparity between the decrement of the wave to be received and the decrement of the receiving aerial circuit. Theoretical considerations and indeed some of my own experiments lead me to the conclusion that, other things being equal, the best condition for receiving a damped train of waves is reached when the decrement of the receiving aerial circuit is equal to the decrement of the received wave trains.

There is another consideration to be kept in mind in drawing deductions from the tests outlined in this paper. When a parallel capacity is substituted for a series inductance, the coupling between the aerial circuit and the detector circuit is automatically altered. To maintain this coupling the same in the

two cases, the mutual inductance between the two circuits would have to be simultaneously reduced. Thus, if $L_1$ is the inductance of the primary of the transformer, $L_2$ the inductance of the secondary, $L_{11}$ the auxiliary inductance in the aerial, $L_{22}$ the auxiliary inductance in the secondary and M the mutual inductance between the circuits, it would be necessary to reduce M in the case of the parallel capacity in the ratio $\sqrt{\dfrac{L_1}{L_1 + L_{11}}}$

The apparent resistance and reactance to alternating currents of a system consisting of a condenser in parallel to a coil is:—

$$R' = \frac{R}{R^2 C^2 \omega^2 + (C L \omega^2 - 1)^2}$$

and

$$X' = -L\omega \frac{R^2 \dfrac{C}{L} + C L \omega^2 - 1}{R^2 C^2 \omega^2 + (C L \omega^2 - 1)^2}$$

where R, C, and L are respectively the resistance capacity and inductances of the loop and $\omega$ is $2\pi n$, where n is the frequency of the current. If $\omega_o$ is the periodicity to which the loop is itself reasonant when isolated, so that $\omega_o = \dfrac{1}{\sqrt{C L}}$ and if the periodicity of the impressed force be m times this, then:—

$$R' = \frac{R}{m^2 R^2 \dfrac{C}{L} + (m^2 - 1)^2}$$

and

$$X' = -L m \omega_o \frac{R^2 \dfrac{C}{L} + m^2 - 1}{m^2 R^2 \dfrac{C}{L} + (m^2 - 1)^2}$$

These are the two quantities which have to be considered in computing the decrement in the case of a condenser in parallel with an inductance in an aerial. Of course, these expressions only apply with complete accuracy in the case of sustained oscillations. But they are approximately correct in the case of damped oscillations except where the decrement is quite large and I have found them to be of considerable utility in the case of the damped trains of waves used in commercial practice.

In the case where the coil of the loop circuit is the primary of a transformer loosely coupled to a detector circuit tuned to the

periodicity $\omega = m\omega_0$ of the received waves, the L of the above expression remains unchanged but the R must be increased by the addition of the amount $\frac{M^2 m^2 \omega_0^2}{R}$.

**John L. Hogan, Jr.:** Dr. Austin's paper opens a field for further investigation which should prove of value. I have no data at hand which either confirms or contradicts his results, but would suggest that in using the capacity-shunted primary I have found what appear to be two distinct cases which in general give opposite actions. When the wave length received is much greater than the natural wave length of the antenna, the distributed inductance of the aerial may be neglected and its capacity can be considered simply as a shunt to the lumped capacity in parallel to the lumped primary inductance. When the received wave is of the same order as the natural wave length of the antenna in question, it appears to be necessary to tune the antenna itself, independently of the capacity-shunted primary, to the wave length desired. This tuning is accomplished by use of a variable loading inductance in series with the aerial, above the upper point of connection to the shunting condenser.

My experiments indicate that relative efficiencies with and without shunting condenser depend not only upon the ratio of incoming wave length to receiving antenna natural wave length (and the mode of connection which this ratio indicates as the better), but also upon the decrement of the received wave as compared to that of the receiving circuit as a whole. I hope that there will be forthcoming additional data of tests in which there is varied not only the ratio of primary inductance to capacity but also the other quantities of which I have spoken.

# DIELECTRIC HYSTERESIS AT RADIO FREQUENCIES.*

By

E. F. W. Alexanderson.

The investigation of dielectric hysteresis at high frequency, which I have taken as a subject for this paper, has been carried out in order to get data of value to the electrical industry, but the phenomena involved have a still more intimate bearing on the construction of apparatus used in radio telegraphy.†

## TRANSFORMER DESIGN.

The design of the high tension transformer, which has been used in the dielectric tests, involved a number of unexpected difficulties, and several models were discarded before one which could be satisfactorily operated was produced. The use of an iron core transformer was not seriously considered for high voltages, because the insulation difficulties, which are great enough without any iron core, would obviously be increased. It is not implied that an iron core transformer may not be found valuable for certain purposes. For instance it may be desired to design a transformer for moderate voltages with substantially the same characteristics as an ordinary low frequency transformer that has a constant transformation ratio regardless of the frequency. However, for the present purpose, where high voltages were desired, no attempts were made to realize such conditions, inasmuch as constant potential characteristics would not be of great value in the measurements of losses. On the other hand it was important to use an apparatus the inherent losses of which were as low as possible, in order to attain great accuracy in the measurements of small quantities of dissipated energy.

In designing the transformer, the feasible alternatives of construction were either the open air type or the oil type. Of these, the open air type was found to be the more practical, partly on account of an inherently greater facility in re-arranging the various coils in order to adapt the transformer for use at dif-

*Presented before the Institute of Radio Engineers, New York, November, 1913.

†With reference to the measurements of dielectric hysteresis, the author wishes to acknowledge the assistance of Mr. S. P. Nixdorff.

ferent voltages and frequencies, and partly because of dielectric losses in the oil itself which would have been so considerable at high voltages that the accuracy of the energy measurements would have been much impaired.

The first transformer which was made consisted of a number of coils designed so as to have minimum internal capacity between the layers of the windings and between the various coils. The insulation losses to be expected are naturally reduced if the internal capacity is kept down to a minimum. Altho the proportioning of the coils was carried as far as could reasonably be expected in this direction, it was found that the insulation losses were excessive. The insulation between the layers of the winding was varnished cambric, and each coil was supported on a frame of fiber. The greatest losses seemed to occur in the fiber spool. It was found that the transformer could be operated only for a short time at a maximum permissible frequency of 40,000 cycles and at about 25,000 volts before it became so hot that it was necessary to interrupt the test. Consequently a new set of coils was made of the same general type, but without the fiber frame and simply taped with cotton. These coils were used in a number of tests at frequencies up to 30,000 cycles. However, it was found that even the varnished cambric insulation between the layers of the winding caused excessive losses. Considerable trouble was experienced from damage caused by corona discharge at high voltages. It was then attempted again to make a fireproof coil, but of somewhat different proportions, by covering the coils with asbestos tape. This proved to be an entire failure, because the heating of the asbestos was excessive even at moderate voltages, and the energy consumption was so great that high voltages could not be obtained at all.

The type of transformer that finally proved successful consists of a considerable number of thin, flat coils wound with wire having a braided cotton covering, but without any further insulation or spacing between layers. The average diameter of the coils is about one foot (30 cm.) and there are 84 turns per coil, each consisting of four wires side by side, the wires being arranged in 21 layers. A voltage of 100,000 can be generated by 18 of these coils in series. Furthermore, it appears that the insulation losses have been entirely eliminated, at least as far as it has been possible to determine them by measurement, and that the losses of the transformer, outside of the $I^2R$ losses, seem to be only the dielectric losses in the air. The coils are insulated as described by nothing but dry cotton, and they are naturally

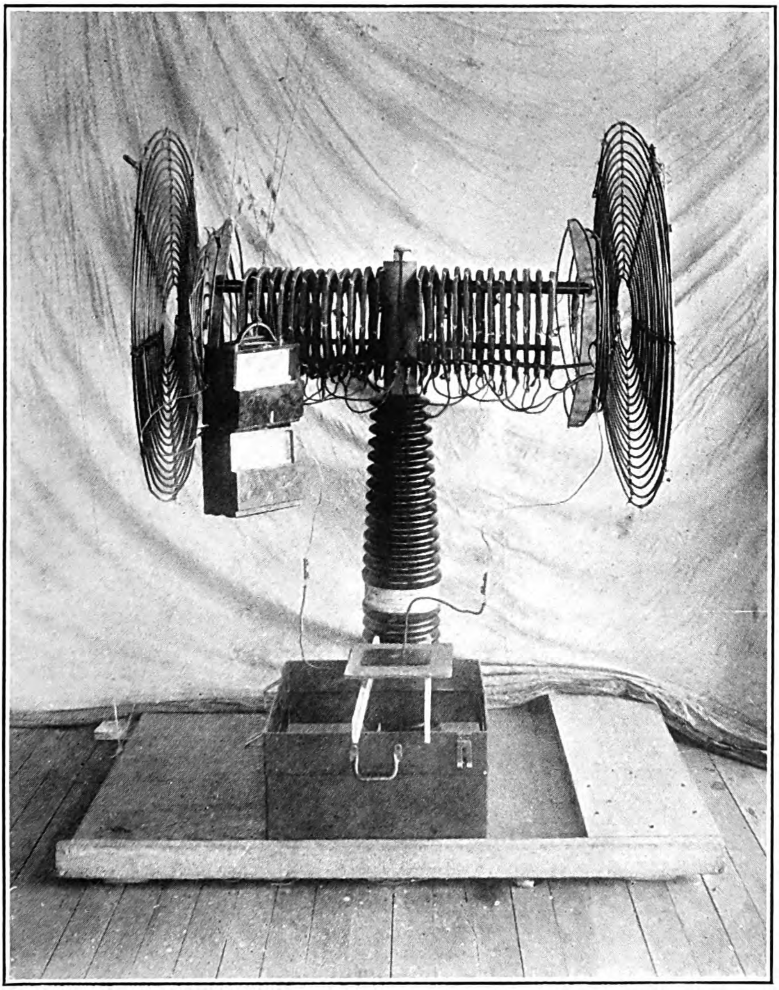


FIGURE 1—Transformer for 100,000 Volts at 100,000 Cycles, Used in Measurements.

susceptible to damage by corona (brush) discharges. It was, therefore, particularly important to construct the transformer in such a way as to protect the coils from exposure to excessive dielectric strains. This has been done by mounting the coils between two end terminals, each sufficiently large entirely to shield the coils from excessive electric strains and to create an electric field of uniform gradient within which the coils are supported. Inasmuch as these terminals or shields are cut by the magnetic field of the transformer, they could not be constructed of solid plates in which eddy currents would be induced, thereby causing serious losses. A convenient structure designed to avoid such losses was made up in the form of a spiral of heavy copper wire with free ends, wound on a wooden frame support. The profile of the frame had an outline with rounded corners, thus avoiding localized dielectric strains in the air. The electrostatic capacity effects produced by these terminal shields is considerable at the high voltages and frequencies used; and it was found, both by calculation and by test, that the capacity of the air circuit would absorb about 200 kilovolt-amperes (K.V.A.) at 100,000 cycles and 100,000 volts. The electrostatic capacity of the terminals was therefore of great importance in connection with the tuning which is absolutely necessary to build up high voltages.

Consequently the number of turns in the coils was so selected as to give inductances fulfilling the requirements for tuning without the addition of an additional external capacity. Any object connected to this apparatus, even a piece of wire attached to the terminals, adds to the electrostatic capacity, and whenever any measurements were made, the added capacity was compensated for by reducing the number of coils in the circuit so as to tune properly at the new voltage and frequency. The assembled apparatus is shown in Figure 1. The transformer coils are mounted on the horizontal supports, which are attached to the top of the large vertical corrugated insulator. The rounded end shield, together with the larger supplementary shields, are clearly seen. The ammeters are suspended by insulating cords in the foreground. In the lower portion of the illustration, a sample under test, between the terminal electrodes, is resting on the top of the oil tank.

If the input (in watts) supplied to the apparatus be measured with the transformers, connecting wire, and necessary instruments in circuit as well as with the sample dielectric properly placed and then if the sample be removed and the input again measured at the same voltage and frequency as before, the

difference between the two inputs is the dielectric loss in the sample. In order that these measurements should be accurate, it is evidently important that the losses in the transformer and its accessories should be kept as small as possible compared with those in the sample. This was actually the case in the measurements that have been made, the total losses in the apparatus being only a small fraction of the total energy that was measured.

## ENERGY MEASUREMENTS.

The method used for measuring the energy in the radio frequency circuit is in principle, the same as the one described in a paper by the author, delivered before the American Institute of Electrical Engineers on "CORE LOSS IN IRON AT HIGH FREQUENCY." The method is based on the use of both voltmeters and ammeters, because accurate wattmeters for such high frequencies have not been developed. The method depends further on a well-known characteristic of alternating current circuits in which sinusoidal currents are flowing. The impedance can be resolved into an "energy component" and a "wattless component," and the wattless component can be completely neutralized by a suitable choice of inductance and capacity. If the impedance of such a circuit is measured, and the ratio of inductance to capacity varied, various values of the impedance can be obtained and plotted as a curve. This curve passes thru a point of minimum impedance for which the inductance and capacity neutralize each other. At that point, the product of volts and amperes represent the energy component or the equivalent resistance of the circuit. This is the condition of unity power factor.

The apparatus which is used for these measurements is adjusted so as to determine this minimum point in the simplest way, without the necessity of plotting the whole curve. Thus, it is possible to make measurements of energy wherein the watts are obtained directly from the product from the volts and amperes, which latter quantities are being observed. The adjustment which is needed to find this minimum point is made by selecting an inductance which is nearly right, and then finding the exact point of minimum impedance by a slight variation of the frequency. The measurement requires simultaneous observation of a voltmeter and an ammeter; and the condition to be looked for is that at which the ratio between the voltmeter reading and the ammeter reading is a minimum. In order to facilitate this observation without recourse to calculation, the

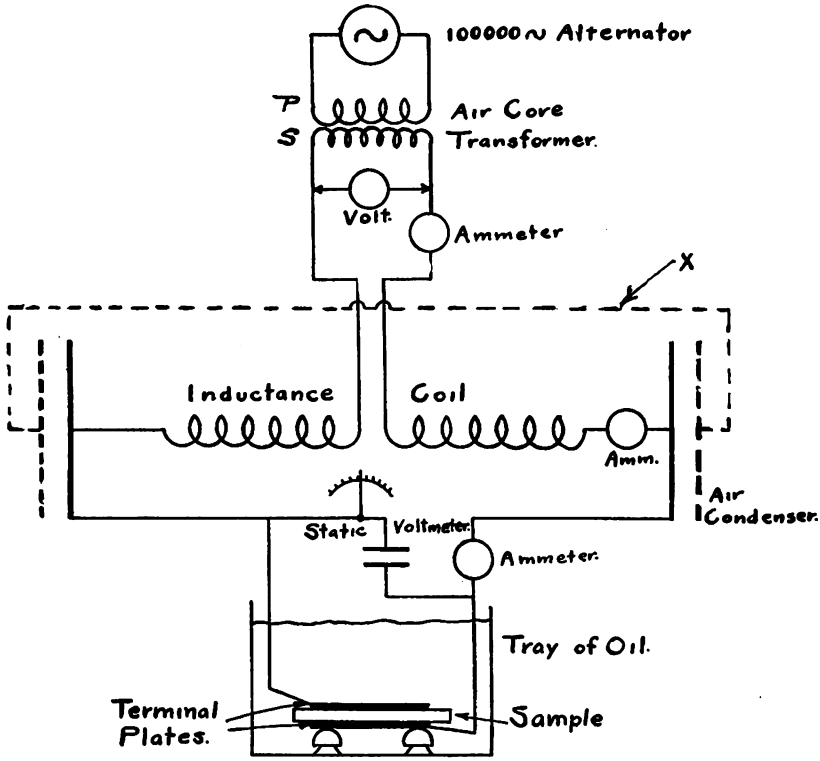



FIGURE 2—Diagram of Connections of Transformer for 100,000 Volts at 100,000 Cycles.

circuit is so adjusted that the voltage remains practically constant while the current goes thru a sharp maximum. It is also possible to arrange the circuits so as to keep the current practically constant while the voltage goes thru a sharp minimum. In other words, the measurements can be made conveniently either on constant potential or on a constant current.

The diagram of connection for a typical arrangement is shown in Figure 2.* The shields or terminals which are used to protect the windings from electrostatic strains are at the same time used as the plates of an air condenser which is needed to create

*The apparatus used is practically a long coil having distributed capacity and inductance thruout its length, and added end capacities. A stationary wave is produced on this coil by exciting it inductively at its central point from a radio frequency Alexanderson alternator. The coil in question is the long horizontal row of flat coils, and the added end capacities referred to are the terminal circular shields.

The stationary wave produced has maxima of potential at the outer ends of the terminal shields and zero potential at the center of the coil S

resonance. If a measurement is made wherein the sample is subjected to a difference of potential, it is convenient to connect the apparatus so as to produce a positive and negative difference of potential at the ends of the transformer secondary with a grounded neutral point. In this case, the energy is introduced at the middle of the high tension coil of the transformer by introducing the energy thru a low tension transformer arranged with a variable ratio of transformation. The energy measurements are made at the point at which the current is led into the high tension coil. The only instruments needed are a hot wire voltmeter and ammeter. It is sometimes convenient to have a static voltmeter connected across the high tension terminals to indicate the voltage impressed on the sample, but it is to be noted that the indications of a static voltmeter sometimes are unreliable, because at high frequencies corona and brush discharges appear at comparatively low voltages. The use of the static voltmeter is not necessary if the inductance of the high tension coil is known, because the voltage can be obtained by multiplying the current by the reactance due to the inductance. It was actually found necessary to use this method in the measurements at the higher potentials. The inductance of the coil was found by calculation, and also by measurement at the lower potentials. This was necessary because at higher potentials the static meters that were available broke down and arced over.

## DIELECTRIC STRENGTH OF AIR.

The phenomena which were observed when the high tension oscillation transformer was operated at a high potential were such as to suggest the immediate conclusion that the dielectric constants of the air differ entirely at radio frequencies from those that have been observed at ordinary frequencies. A further analysis has led to a modification of those conclusions, at least in part; and there are several indications that all the abnormal phenomena at very high frequencies can be explained as secondary effects. A theoretically ideal condition may be supposed for which air would have exactly the same characteristics at radio frequencies as it has at audio frequencies. Whether this is the

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whereby it is inductively coupled to coil P and the alternator. In order to produce this stationary wave, it is necessary that the inductance of the long coil, together with its distributed and end capacities, shall cause resonance at the given frequency.

The distributed capacity of the long coil and of the end shields is indicated by the dotted line (X) of Figure 2. This capacity is, of course, only present in effect; and is not actually definitely connected in setting up the apparatus.—(EDITOR'S NOTE.)

case or not, the fact remains that for all practical purposes the phenomena at very high frequencies are radically novel, and any apparatus which is to be subjected to such high frequencies must be quite specially designed. Constants obtained by observation must be known for the materials used, as well as the proper proportioning of parts that are to be used in the radio frequency circuit. For instance, at 100,000 cycles, a small wire is surrounded by so much corona discharge even at a potential difference relative to ground of 15,000 volts, that such potentials can be handled without excessive loss only when observing great precautions. Thus, we must use a cable of at least the thickness of a lead pencil and protect all projecting corners by shields of tin foil. On the other hand, we find practically the same constants for the dielectric strength of air as have been found for ordinary frequencies if the measurements are based on the arc-over distance between spheres of polished brass. The arc-over distance for a pair of spheres of 5 inches (12.9 cm.) diameter was found to be 3 inches at 100,000 volts and 100,000 cycles, and no corona was noticed on the spheres before the arc took place. The difficulty in arranging these measurements consisted in producing this potential difference and conducting it to the spheres without excessive static discharge from the terminals and leads. This could be accomplished only by placing the spheres within the uniform electrostatic field that is created between the transformer terminals or end shields which are used to protect the coils on which the potential is generated. This is obviously an artificial condition and it is safe to say that, for practical purposes, it is not possible to conduct a current, even for short distances, at a potential difference approaching 100,000 volts at such radio frequencies.

## DIELECTRIC LOSSES IN INSULATION.

In measuring the losses in solid dielectrics, it was necessary for the reasons given above to immerse the sample under test in oil. The attempts to make measurements in air failed because the air space between the terminals and the sample gave rise to such an excessive loss of energy from corona discharge that the sample would crack or burn, because of the heating, at a much lower potential than that corresponding to the true dielectric strength of the material. Commercial insulation, which successfully resisted 100,000 volts at any ordinary frequency, cracked after being subjected for about a minute to 15,000 volts at 100,000 cycles, because of the heat of the corona produced at the metallic

terminals. Tho immersion of the sample in oil makes it possible to measure the losses in the material itself without interference by secondary phenomena, it must be remembered that in practice insulators of existing designs have no such protection, and may be subjected to the local heating caused by corona. A test of commercial insulators under oil will, therefore, not give fair indications of their values, even tho the dielectric characteristics of the material itself might, as determined by such a test, be apparently quite satisfactory.

Even when measurements are made under oil, the insulator is apt to break down because of deterioration caused by the heat generated in dielectric hysteresis, rather than because of dielectric strain. The same effect is found to occur when oil is used and the arc-over occurs at much lower voltages than those corresponding to ordinary frequencies. This is another instance where the apparently different characteristics are dependent for their difference on secondary phenomena. It is probable that under theoretically perfect conditions the same dielectric strength would be found at high frequencies as at low frequencies, and in oil and solid dielectrics as well as in air. This would be the case if the incidental phenomena of corona and heating could be eliminated. In order to be able to apply systematic and scientific methods to the design of radio frequency circuits, the author has made a series of measurements of dielectric losses for different insulation materials. These results are presented on the curve sheets in order to give the designers data for calculating the insulation losses in each part of a complete structure designed for use at such very high frequencies.

All the measurements have been made on samples 0.6 cm. (0.25 inch) thick, and with an area of 200 sq. cm. (30 square inches). The samples were in every case immersed in oil for reasons that have been explained. The insulation materials which were investigated are mica, glass, paper, varnished cambric, and asbestos. A general comparison between the characteristics of these materials is given by the curves of Figure 3 to Figure 7 inclusive. Figure 3 gives a comparison between the dielectric permittivities of the materials that were measured. This information is given by plotting the amperes of displacement current that would flow through a centimeter cube under a potential difference of 10,000 volts against the frequency. Figure 4 gives the watts loss in a centimeter cube for 10,000 volts at different frequencies. For the sake of comparison the losses of each of the materials, among which mica gives the lowest values and

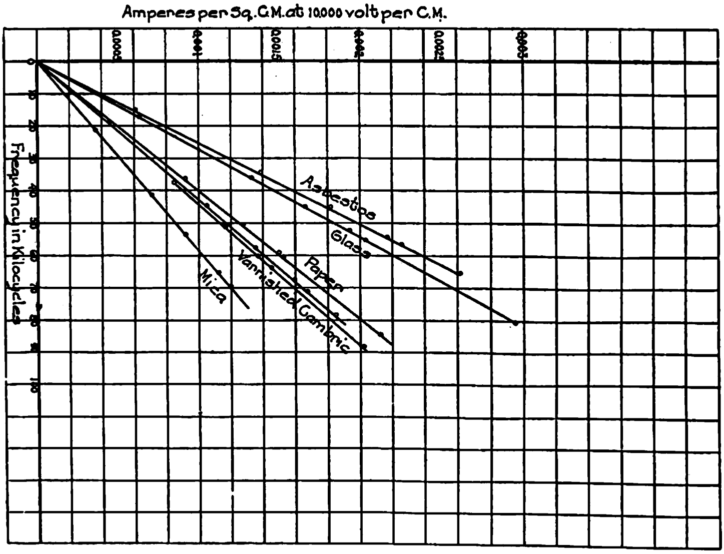



Fig. 3
Dielectric Permittivity

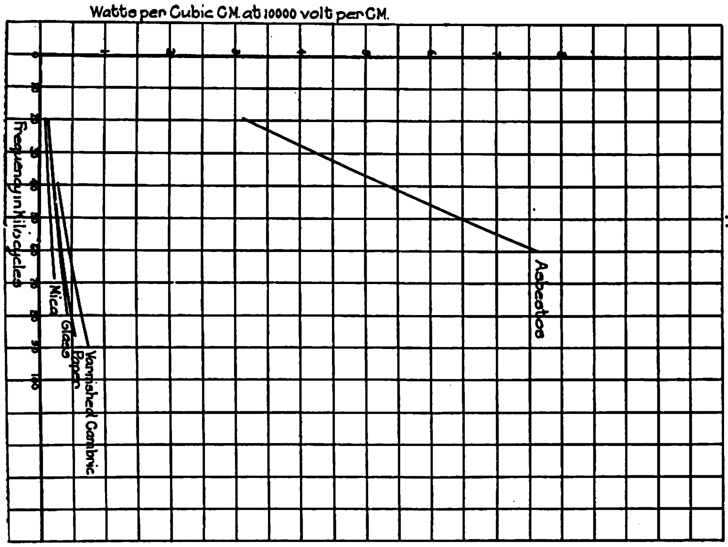



Fig. 4
Comparison of Dielectric Losses
in Different Materials

asbestos the highest, are plotted on the same curve sheet. It is noticeable from this comparison that asbestos has a loss which is so far the greatest as to make it appear to be in a different class. For a closer comparison of the ordinary insulation materials; namely, mica, glass, paper, and varnished cambric, the losses per centimeter cube are shown on Figure 5. On Figure 5 is also given the power factor of each of these materials at the different frequencies. The power factor is the ratio between the watts loss and the volt-amperes absorbed.

It was found, in examining this data, that the figure for the power factor gives the most important and characteristic information of the insulation materials so far as dielectric losses are concerned. As seen from the curves the power factor is substantially constant at all frequencies and all voltages. This fact naturally leads to some interesting speculations as to the real nature of the dielectric losses. The dielectric losses are usually called dielectric hysteresis, but the question has been raised whether this is an appropriate name; and the data for dielectric losses has, by several investigators, been given in a form that would indicate that the nature of the losses is such as would be presented by a resistance in series with the capacity, while others have indicated it as a shunt resistance. A series resistance would give a power factor increasing in proportion to the frequency and a shunt resistance a power factor decreasing with the frequency.

The data obtained shows a power factor that increased slightly with the frequency for glass, mica, and paper; whereas the power factor for asbestos decreases. If we assume that the losses consist of a true dielectric hysteresis as well as series resistance and shunt resistance, it appears that that dielectric hysteresis, which is characterized by a constant loss per cycle, and consequently a constant power factor, is by far the predominant portion. In addition to this, it would appear that mica, glass, and paper have a slight series resistance and that asbestos has a shunt resistance, which is large enough to be slightly predominant over the series resistance. The losses in all the insulation materials are dependent upon the temperature; and a variation in losses due to this cause is apt to introduce differences considerably greater than the actual changes in power factor due to a series resistance or a shunt resistance. It can therefore be said that for practical purposes, the losses may be considered as if they were due to a true hysteresis, at a constant power factor, at all frequencies and all voltages. After the general data has been obtained for each sample, the test was carried further to the point of break-

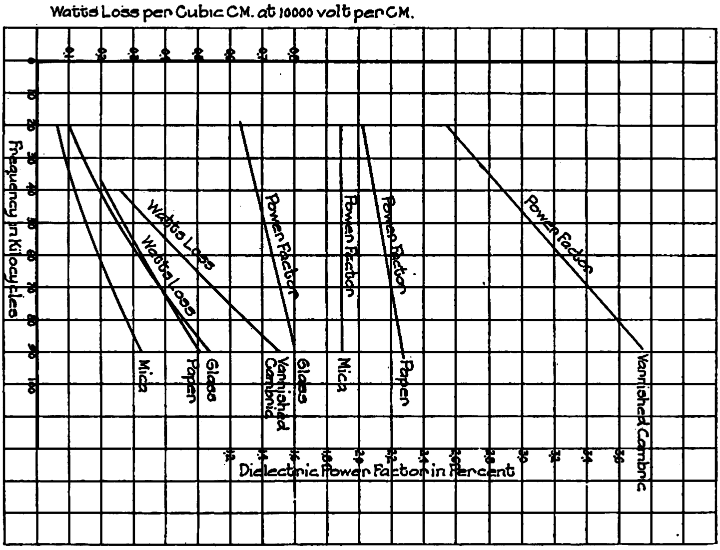



Fig. 5
Losses per Unit Volume and Dielectric Power Factor

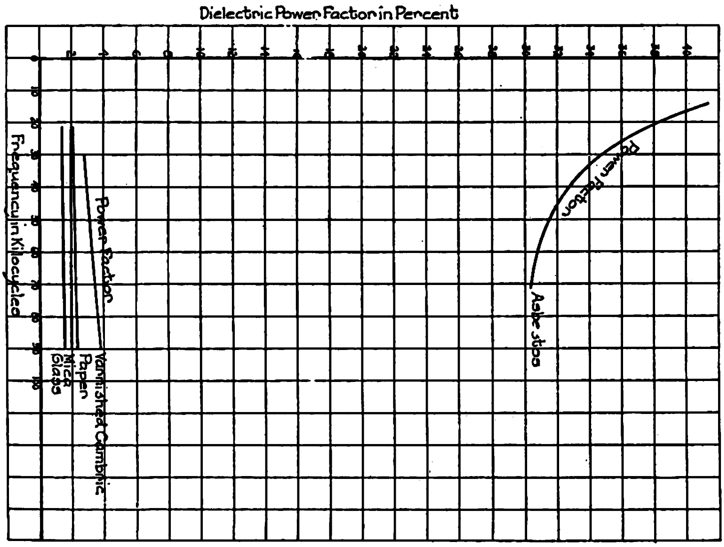



Fig. 6
Comparison of Dielectric Power Factor in Different Materials

down of the insulation. It is found that in each case, before the actual breakdown, a certain rise occurs in the power factor, and a slight decrease in the dielectric capacity. This rise of power factor is due to the increased heating, which becomes cumulative when the temperature has reached a certain limit. A set of average curves for the increase of power factor before the breakdown is shown in Figure 7 for the different materials. These curves show that the different materials, regardless of their inherent power factor, break down after the power factor has reached substantially the same value. The limits of power factor, given by the curves of Figure 7, therefore depend more upon the method of cooling of the particular samples that were used than on any inherent characteristic of the material. To illustrate the change in the power factor, the curves are plotted for the actual volts applied to a sample 0.6 cm. thick. The results can be duplicated only if the sample under test is cooled in the same way.

Figures 8 to 12 inclusive give the results of the measurements from which the above conclusions are drawn. The curves are plotted for each set of measurements, so that the reader will have the opportunity to form an opinion of the magnitude of the variations, which are due to voltage and frequency values, and also of those variations that were incidental to the experimental procedure which were due to rise of temperature. The shape of the power factor curve for each set of measurements is not sufficiently continuous to allow any definite conclusions to be drawn as to the law of variation of power factor with the frequency; nevertheless the assembled set of data indicate a general shape of the curves quite clearly.

With regard to the losses in mica, it should be noted that the samples used were of commercial built-up mica. Tests have since been made of clear mica for condensers and it was found that there is a wide variation of losses depending upon the grade of material. Measurements of power factor in various grades of mica used commercially for insulation have shown variations from 0.5 per cent. power factor to 7 per cent. power factor. Most commercial grades of mica fall between 1 per cent. power factor and 3.5 per cent. power factor, and it may be assumed that such mica as might be selected for condensers should have a loss of not more than that corresponding to 1 per cent. power factor.

Fig. 7
Rise of Dielectric Power Factor
Before Break Down

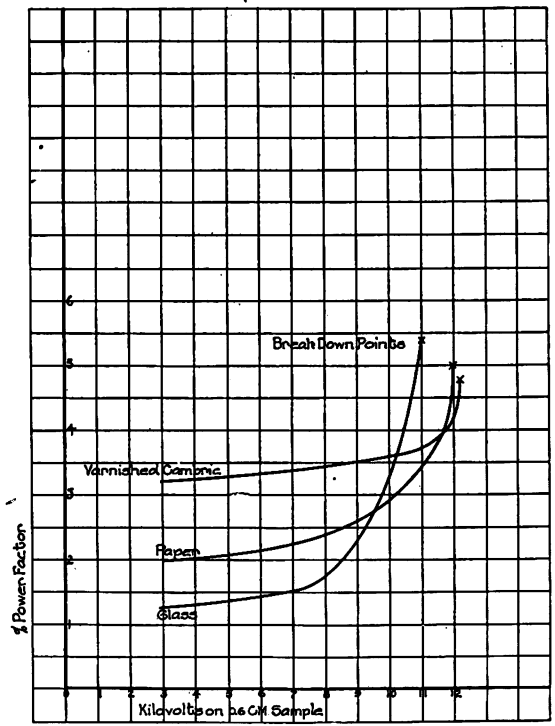
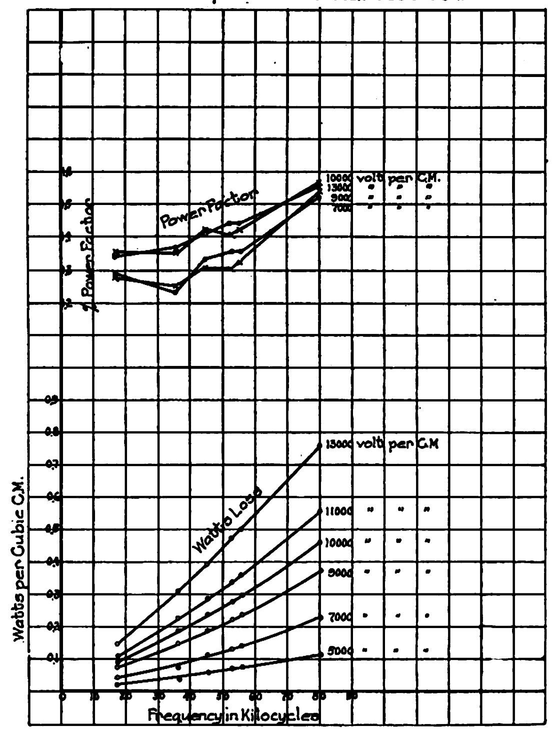



Fig. 8
Results of Measurements
2 Sheets of Glass – Total Thickness 0.59 CM.



It has usually been assumed that air has no dielectric hysteresis whatever. While this may be so in a theoretical sense, the measurements made by the author for the purpose of determining the dielectric losses in air indicate that even the most perfect air condensers which it has been possible to establish, have losses which are easily measurable, and within the range of the apparatus used for this purpose. The losses that have been measured in different air condensers vary considerably in magnitude, and they depend principally on the sharpness of the corners and edges. For instance, if sheets of tinfoil about 6-inch square (15 cm.) are suspended at about 2-inch (5 cm.) distance, they show a loss as high as 1 per cent. Round copper plates of about $\frac{1}{32}$ inch (0.8 mm.) thickness and 2 feet (60 cm.) in diameter suspended at 6-foot (1.8 m.) distance from each other show a loss of about 0.4 per cent. The end shields of the high tension transformer, which are shaped so as to avoid, as far as possible, any local dielectric strains, show a loss of 0.2 per cent.; and a pair of brass spheres suspended at 0.5 inch (1.3 cm.) distance also show 0.2 per cent. A part of this measured loss may be due to incipient corona which cannot be detected, and a part of it may be due to actual dielectric hysteresis in the air space. However, it is certain that a part of it is due to radiation into space. This was proven conclusively by some measurements on the end shields of a transformer when in one case for which these losses appeared to be unusually high. This was found to be due to a fine wire which was suspended about 5 feet (1.5 m.) above the apparatus, but entirely disconnected. It may be possible to design an apparatus so as to separate and measure these losses. The radiation losses could be eliminated by enclosing the whole apparatus in which the high voltages are generated in a metal cage constructed so that no losses could occur due to the short circuits cut by the varying magnetic flux; and the losses due to incipient corona could probably be eliminated by comparing the losses in air circuits of different lengths but with the same voltage gradient at the terminals.

A demonstration which is both unexpected and striking to the effect that the fundamental loss which has been found at low frequency remains applicable at extremely high frequencies, is found in the measurements of energy loss due to corona around a small wire. The measurements were made on two wires, each 40 inches (1 m.) long, suspended free in air at a distance apart of 2 feet (60 cm.). The wires were 0.01 inch (0.4 mm.) in diam-

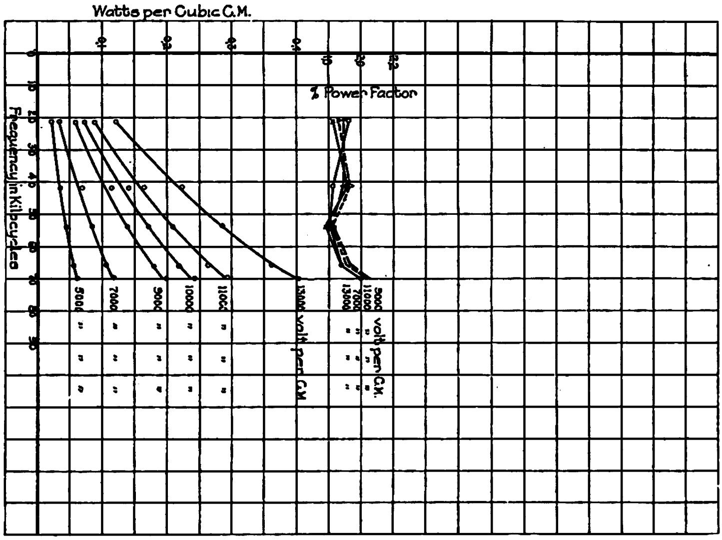



Fig. 9
Results of Measurements
4 Sheets of Mica – Total Thickness 0.55

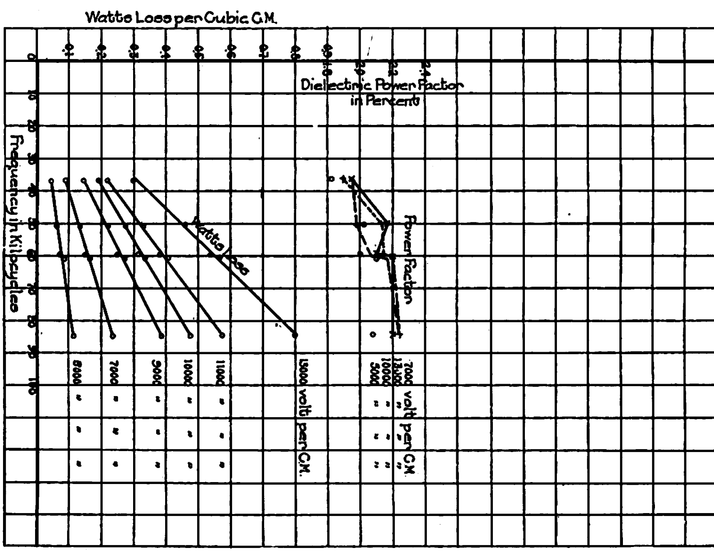



Fig. 10
Results of Measurements
2.5 Sheets of Paper – Total Thickness 0.6 C.M.

eter. The measurable corona loss was first evident at 15,000 volts difference of potential; and increased very rapidly so that at 27,000 volts, the energy absorption was nearly 0.5 kilowatt. It is the quantitative magnitude which is surprising in this case; and it is difficult to imagine that this large amount of energy is radiated from such fine wires without bringing them to incandescence. However, there appeared to be no evidence of heating on the wire itself, and the wires were surrounded by the blue flame of the corona, which was well visible even in bright daylight. The most interesting feature of these results is the fact that they agree remarkably well with the laws of the corona as developed theoretically by Mr. F. W. Peek, Jr., and given in a paper* for the American Institute of Electrical Engineers in 1911. Both the point at which the corona begins, and the shape of the sharply rising curve of losses at increased voltages are in agreement with calculations. An agreement has thus been found between phenomena occurring at low frequencies and at radio frequencies, not only as to arc-over distances between spheres of polished metal but also for the measurement of corona loss on wires. This justifies confidence in such theoretical assumptions as may be necessary in order to determine by calculation the losses under various conditions that are not conveniently subjected to laboratory measurements. In view of this, I believe that calculations for a number of phenomena, which are at present uncertain in nature, can be made on a semi-theoretical basis, thereby furnishing practical data for the design of insulators and conductors which are to be subjected to very high frequencies.

In the first attempts to make measurements of corona losses on wires, as was previously mentioned, some difficulty was found in suspending the wires. If a cotton string was used, it soon caught fire and burnt off because of the heating caused by the corona flame. It was then attempted to use a small porcelain insulator suspended by a cotton string. In this case, there appears to be an excessive corona discharge between the wire and the insulator at voltages lower than that of the appearance of corona on the wire itself, and the insulator eventually heats up sufficiently to break it into loose pieces. The heating of the insulator itself would, of course, interfere with the accuracy of the measurements that were to be made. As a practical method of suspending the wires without introducing extra losses, they

*"The Law of Corona and the Dielectric Strength of Air," F. W. Peek, Jr., Proc. A. I. E. E., Vol. XXX, Part 1, Page 1485.

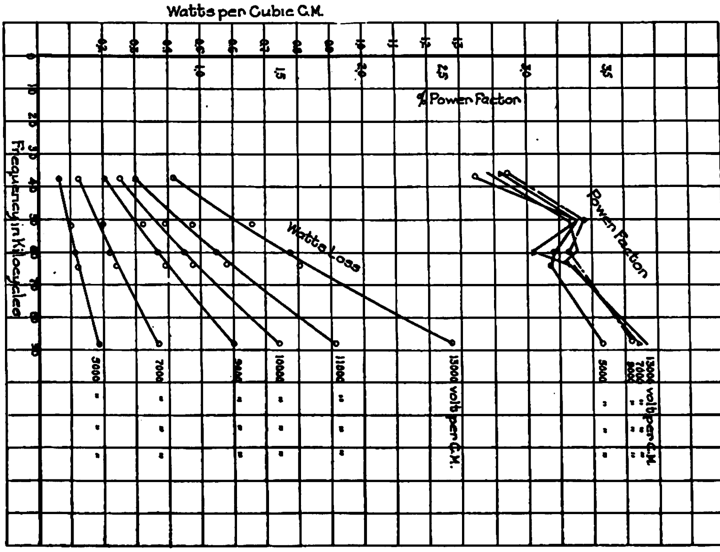



Fig. 11
Results of Measurements
21 Sheets of Varnished Cambric
Total Thickness 0.53 C.M.

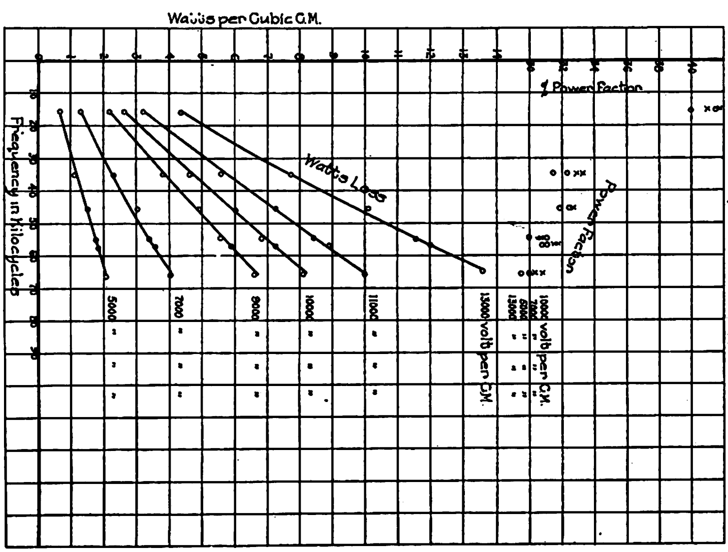
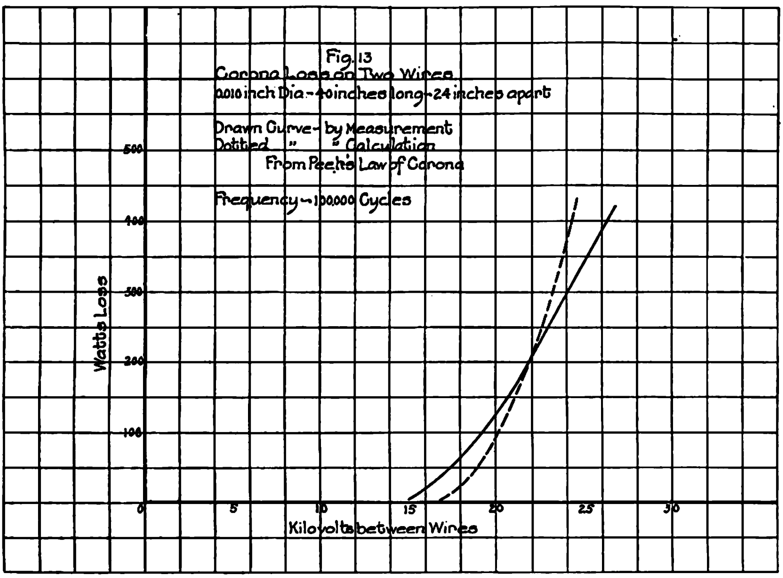



Fig. 12
Results of Measurements
8 Sheets of Asbestos—Total Thickness 0.6 C.M.

were tied to a cotton string, and the joint wrapped with tinfoil to a considerable thickness and in such a shape that the point where the wire touched the metal was surrounded by a bell shaped shield of tinfoil. In this way the corona discharge from the terminals was not only reduced but also kept away from the joint between the wire and the metal. While it is in practice necessary to use insulators in supporting wires there can be no doubt that the success of the apparatus depends greatly upon the design of the insulators and the effectiveness with which losses due to local heating are avoided. The excessive corona losses at the point where the metal touches the insulator can




easily be explained from a consideration of the dielectric characteristics of the materials. We may, for instance, assume that the insulator has a dielectric constant five times as high as the air, and that the layer of air between the metal and the insulator is not of sufficient thickness to change the distribution of the electric field in the insulator. If the wire were totally embedded in the dielectric the higher permittivity of the insulator would cause five times as great a current to flow from the wire into the dielectric as would flow if the wire were suspended in air, but the distribution of potential in the insulator would be the same as the distribution of potential when the wire is totally sur-

rounded by air. If, however, there is a small layer of air between the wire and the insulator, the current flowing thru this layer of air is five times as great as it would have been if the insulator had not been present, and consequently the potential gradient in this layer of air becomes five times as great. In this case it is to be expected that corona would appear locally at a voltage only one-fifth as great as the voltage that would produce corona if the wire were suspended freely in air. The measurements of corona losses in a 10 mil (0.4 mm.) wire, as well as theoretical considerations, indicate that corona should commence at 15,000 volts between such wires suspended at a considerable distance. In other words, corona begins when each wire has a difference of potential of 7,500 between it and the surrounding air. If such a wire be brought close to a large insulator, which has a permittivity five times that of air, it is to be expected that corona would appear at a voltage one-fifth as great as before, that is at 3,000 volts potential difference (or 1,500 volts above ground potential, provided that one side of the insulator is grounded). This agrees substantially with the results of observation, and tho it may be desirable to collect more empirical data on this point, it should be possible to extend this line of reasoning to phenomena which cannot be subjected to measurements, thereby gaining a quantitative knowledge of many phenomena which have an important bearing on the proper functioning of the very high frequency circuit.

TABLE 1.

REPRESENTATIVE VALUES OF DIELECTRIC LOSSES.

| | Power Factor per cent. | Watts Loss per cm. cube at 10,000 volts per cm.; per kilocycle. |
|---|---|---|
| Clear Mica for Condensers, | 1.0 | 0.0016 |
| Built-up Mica, | 1.9 | 0.003 |
| Mica, | 1.9 | 0.003 |
| Glass, | 1.4 | 0.005 |
| Paper, | 2.2 | 0.0055 |
| Varnished Cambric, | 3.3 | 0.0080 |
| Asbestos, | 3.0 | 0.13 |

(September 14, 1914.)

**SUMMARY:** The development of a transformer for 100,000 volts at 100,000 cycles is described in detail. The successful construction is given. The necessary even potential gradient along the high tension secondary of the transformer is provided by special end shields. The dielectric strength of air is determined at radio frequencies, and the novel behavior of air at these frequencies is described. The methods of measurement of dielectric losses

**of various materials are given. The materials tested show that the predominant loss is constant per cycle (i. e., it gives rise to a constant power factor). Mica, glass and paper show also a slight equivalent series resistance (corresponding to a power factor increasing with the frequency); asbestos a shunt resistance. The break-down conditions of the various dielectrics were studied. The dielectric hysteresis of air is measured, and it is found that radio frequency corona as well as arc-over distance are subject to the same laws as at audio frequencies.**

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## DISCUSSION.

**Robert H. Marriott** (*Chairman*): On behalf of The Institute of Radio Engineers, I wish to thank Mr. Alexanderson for presenting this paper before us. It is of great value to workers in the radio field.

**H. E. Hallborg**: There are three recent papers; one by Fortescue read before the American Institute of Electrical Engineers, and those by Dr. Austin and Mr. Alexanderson read before the Institute of Radio Engineers, which mark three milestones in our emancipation from insulation difficulties. These papers should certainly be read by all radio engineers.

Our methods in the past have been empirical in the extreme. If we found that one foot of insulation would not withstand 100,000 volts, we simply added an additional foot of insulation. The effect might well be the opposite of that desired. It is very important in such problems to consider the stresses in the dielectric (that is, the electric field intensity). There is no doubt that these problems will eventually be worked out in the same systematic fashion as that in which problems involving the magnetic circuit containing iron are now handled.

The total dielectric field is represented by the product C times E (C, of course, is capacity and E voltage). Fortunately for most insulators, the value of C is small, so that in spite of the application of a high voltage the total dielectric field remains such that the dielectric flux per unit area is very low, and the danger of failure therefore remote. When, however, the value of C becomes appreciable, as in a condenser, then the application of even a moderate voltage sets up a dense field and the flux per unit area becomes high. Hence, it is readily seen that it is by no means a just test to compare insulation by voltage test alone since there may be a vast difference in field intensity, and the insulation that is found to be the poorer by this test may really be the better when densities are taken into account. We compare samples of transformer iron for losses at equal densities; why not dielectrics? I believe that the time is com-

ing when we will assign a particular density to a particular frequency range for all radio dielectrics at least.

I have had occasion to make some measurements following the method outlined by Dr. Austin in a somewhat modified form, adapted to commercial practice. The energy in a circuit containing an air condenser was compared with that in a circuit containing a condenser having the dielectric under test, the circuit being otherwise the same. In making these measurements, the percentage current absorption per square inch of dielectric cross section could be determined, and thus the most desirable insulator selected for the purpose at hand. Measurements were made using a quenched spark set, and at a frequency of 500,000 cycles. The difference in the losses in what are ordinarily considered good insulators was found to be enormous by these tests. Indeed, most of the so-called "good insulators" were worthless when used at radio frequencies.

Insulating oils were also found to possess substantial dielectric hysteresis. This varied markedly with the sample tested, the measurements yielding results differing by as much as ten to one. Some of the losses are probably due to water in the oil, but another component is probably due to some inherent quality of the oil.

Insulators of glass, which would satisfactorily withstand a certain voltage in air without rupture, I found would break down in oil, probably because of the concentration of the brushing along the glass surface. When in oil, the brushing is concentrated along the edges of the conductors carrying the applied potential difference; which results in excessive heating at these points, and consequent breakdown of the glass. The failure of glass plate condensers immersed in oil is exactly proportional to the relative hysteresis losses of the oils; the greater the loss in the oil, the lower the rupture voltage of the glass plate condenser. This is probably due to unequal expansion in the glass caused by dielectric saturation of the oil which starts heavy brushing at the edge of the foil, as failure is usually in the form of a crack, seldom a straight puncture.

In working with electrostatic voltmeters, I have experienced considerable trouble. One instrument gave unreliable results because its capacity changed the constants of the circuit in which it was connected. This instrument was very unsuitable; in fact, it gave half scale deflection when used on high frequencies with only one lead connected.

I should like to consider the matter of using iron in radio coils, and oscillation transformers as mentioned and proposed by Mr. Alexanderson. I remember trying this experiment some years ago when a bundle of good quality transformer iron was inserted in an aerial loading coil operating at a frequency of 200,000 cycles. The inductance value naturally increased greatly; but on retuning the circuit by changing only the number of turns in the loading coil, I found that the tuning had become very broad and the radiation considerably lower because of the increase in damping resulting from the insertion of the iron. I would also quote as an objection to the use of iron cores the fact that the voltage per turn would run so high that the smaller size of coil for a given inductance would be counteracted by the fact that a solid insulation would be necessary between turns, thus producing more of the losses that Mr. Alexanderson has just been telling us about.

**Ralph H. Langley**: Has fatigue of the dielectric been noticed; that is, have the losses been noticed to increase with time? In other words, was the power factor of the circuit a function of the time?

**E. F. W. Alexanderson**: As regards the electrostatic voltmeter, I may say that I have had experiences similar to those of Mr. Hallborg. There are two types of electrostatic voltmeter. In one of these types, the distance between the plates is fixed but the opposing area variable. This is the Kelvin interleaving plate electrometer. Such electrometers are very unreliable partly because of the large corona losses and partly because of the high, and markedly variable, capacity. The second type of meter has constant area between the plates but variable separation. These are found to be fairly satisfactory.

In testing the oil, it was found that the loss was 0.7 per cent. per cubic inch at 20,000 volts per inch stress. It was not possible to increase this stress beyond the value given, because thereafter the losses increased very rapidly, the oil began to boil, and breakdown followed. It will be seen that the eventual breakdown was thus due to heating, and this may be called a sort of fatigue. The oil does not seem to break down immediately, but may after a considerable time lag. This may be due to the continued storage of heat in the dielectric, which is therefore weakened. It is difficult to differentiate between the fatigue which is due to heating and that which may be due to other effects.

**H. S. Osborne:** With reference to the subject under discussion this evening, the recent work of Professor Ryan of Leland Stanford University, may be of interest. He has been looking for an explanation of some of the curious insulator breakdowns which occur on high voltage transmission lines. He experimented with about 100,000 cycles at 30,000 volts. In making tests with small porcelain knobs, which at ordinary frequencies flash over at perhaps 10,000 volts and cannot be punctured, it was found that 100,000 cycles and 30,000 volts did not cause a flash over, but gradually punctured the knob by burning a minute hole thru it. A 60,000 volt line insulator was also tested. Altho this insulator did not break down at the usual power frequencies and flashed over at about 200,000 volts, when subjected to the radio frequency, a small hole was burned thru the insulator from the groove to the pin.

**E. F. W. Alexanderson:** Such tests must be of considerable interest to radio men. We have made similar tests of high voltage insulators, using a relatively fine wire for localizing the heating at some point of the insulator.

**Alfred N. Goldsmith:** In connection with values of the power factor given by Mr. Alexanderson, it is interesting to compare them with similar results obtained by Max Wien in May, 1909. In working with air, Wien used compressed air condensers, the separation of the metal tubes being 3 mm., the pressure 20 atmospheres, the capacity 0.0017 microfarad, and the breakdown voltage 40,000. The condenser was charged quickly by an induction coil in these measurements. The decrements were always carefully obtained from the same points of the resonance curve. In order to avoid the spark decrement and to check up the measurements, the impulse excitation method of energizing the condenser circuit was also tried. In order to test the oil as a dielectric, thoroly dried paraffin oil was poured into one of the air condensers. The breakdown voltage then became 30,000. The glass condensers tested were Leyden jars, which showed considerable corona even at 9,000 volts. They could be run as high as about 25,000 volts. The brush losses were separated with these jars by testing them again when immersed in oil. In all these measurements, the frequency was of the order of magnitude of 1,000,000 cycles. I have obtained the value of the power factor from Wien's values of the decrement by the usual equation:

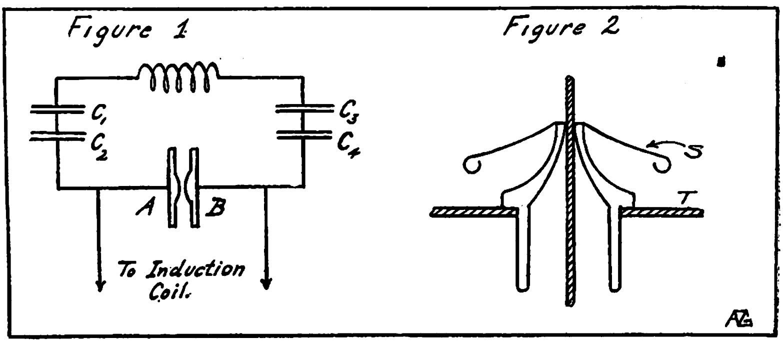
(Decrement) $= \pi$ (Power Factor).

The following table gives a comparison of the results:—

| Material | Power Factor (Wien) Less than | Power Factor (Alexanderson) | Testing Voltage (Wien) | Testing Voltage (Alexanderson) |
|---|---|---|---|---|
| Air, | 0.03% | 0.2% | 40,000 | 100,000 |
| Oil, | 0.06% | 0.6% | 30,000 | 20,000 |
| Glass, | 0.05% | 1.4% | 9,000—25,000 | 10,000 |

Wien calls attention to the fact that the increased corona and hysteresis losses apparently increase the spark decrement at high potential very markedly. Most of the earlier investigators were not aware of this, and their values for the spark decrement at high potentials are much too large, and of no value.

The methods used by Wien in experimenting at frequencies of about 2,000,000 cycles and voltages up to 140,000 may be of interest. The circuit arrangement is shown in Figure 1. The




inductance, L, consisted of 0.5 cm. copper wire wound into a helix 40 cm. long and 50 cm. in diameter. This helix was hung on dry wood supports by silk threads. At the highest voltages used, the leads to the condenser began to brush. To prevent this, they were covered with wax to the necessary extent. The condensers $C_1$, $C_2$, $C_3$ and $C_4$ were compressed air condensers each capable of withstanding 40,000 volts. A and B are the sparking electrodes, which are of large size. They consist of brass plates 22 cm. in diameter, in the center of the plate a rounded piece of zinc 0.45 cm. high being soldered. Such large electrodes are needed if low decrements are to be obtained at high voltages. It was found that the spark decrement decreased from 0.039 at 31,400 volts to 0.018 at 136,000 volts.

An ordinary inductively coupled set was then arranged. The induction coil supplied 13.4 watts to the condensers (7 discharges per second). When working at 150 meters and 72,000 volts, with a properly arranged secondary, the efficiency from induction coil to secondary circuit was 82 per cent. This result is surprising to those who have believed that the efficiency of such ordinary spark sets is limited to 10 or 15 per cent. It may be mentioned that the highest efficiency claimed by the Telefunken Company for a quenched spark set from transformer to antenna is 84 per cent.

The means which Mr. Alexanderson has used for preventing a concentration of the electric field; namely, enlarging the conducting surface and extending it away from the point at which the brushing tends to occur, has been used by the Telefunken Company in the Rendahl deck leading-in insulator, a cross section of which is shown in Figure 2. Here S is a metal shield which extends over the conducting deck, T, and thereby produces a more even electric field, thus avoiding an excessive load at any point of the insulator.

The problem of insulation at radio frequencies and even moderate voltages will surely become of increasing importance, particularly when such devices as the Goldschmidt alternator and the Arco frequency transformers, both of which must be constructed of reasonable dimensions, become more commonly used.

**H. E. Hallborg**: In making tests on the ability of insulators to withstand high voltages at radio frequencies, it is necessary to continue the test over a period of time which will be sufficient to show any effects which may result from the gradual accumulation of heat. The true heating effects will not appear in a few seconds, tho in condensers the hysteresis effects will show more quickly than in insulators generally. Tests made on an ordinary molded insulator show that, altho the insulator may behave well for the first few minutes, if the test is extended over five or ten minutes, the insulator may fail completely. One sample of molded insulator, for instance, finally curled up and rolled off the table. It is evident, therefore, that in testing the characteristics of insulators at radio frequencies the time element must not be neglected.

**J. L. Hogan, Jr.**: The data given by Mr. Alexanderson, especially when confirmed by further experiment, will prove of great value to radio designers. The need of more intelligent

planning of insulators than is practiced in some quarters is well shown by the many instances of failure under high frequencies after stringent low frequency tests have been passed satisfactorily. The experiences of the Federal Telegraph Company, which often have been duplications of the effects described by other speakers this evening, show the absolute necessity of considering the form of the static field surrounding conductors which are to be kept apart. Several A. I. E. E. papers have treated these matters recently, and I cannot urge too strongly that all radio engineers familiarize themselves with the principles involved, with especial attention to the important work described in the last A. I. E. E. paper of Mr. Fortescue (in the Proceedings of the American Institute of Electrical Engineers, 1913, Vol. XXXII, Part 1, page 759).

**Guy Hill**: Has Mr. Alexanderson tried measuring the insulation losses in air by putting the insulating material between spheres, instead of immersing it in oil?

**E. F. W. Alexanderson**: This was not attempted. If the metal electrodes touch the insulating material the results are apt to be vitiated because of the local concentration of the field and the resulting heating; that is, a redistribution of the electric gradient occurs. In air, we should also get corona effects which would materially affect the results. Altho the air might be strong enough normally, the concentration of the field might cause a breakdown.

**Robert H. Marriott**: In connection with the subject of insulation, I should like to refer to a paper by Stanley M. Hills. (Proceedings of The Institute of Radio Engineers, Vol. I, Number 1, page 14.)

**Lester Israel**: What material was finally used for supporting the transformer coils?

**E. F. W. Alexanderson**: Cotton tape was used for separating the turns of the pancake sections of the transformer. Each of the pancakes was held together by a radial application of tape at several points of the inner and outer circumferences. The coils thus formed were rather loose, but satisfactory in practice. They were merely hung on a wooden stick. It was necessary to limit the drop of potential along this stick else burning occurred on the wooden surface.

**An Auditor:** Were the transformer shields wound on an insulating material?

**E. F. W. Alexanderson:** These spiral shields were supported on wooden templates which did not extend outside of the shields. It is necessary that the wood used in such work be well treated.

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A motion was made, seconded and passed that the thanks of The Institute of Radio Engineers be extended to Mr. Alexanderson.

# SPECIFICATIONS FOR STEAMSHIP RADIO EQUIPMENT*.

By

Robert H. Marriott, B. Sc.
*Past-President of the Institute.*

I have repeatedly argued before you that steamships are not so well equipped with radio apparatus as they should be, that the apparatus in use is not so powerful, efficient or reliable as it should be from the standpoint of commercial and distress requirements taken in conjunction with the present knowledge and available apparatus.

I have particularly tried to point out that it is absurd to give a steamship a comparatively strong voice for ordinary conditions and a hoarse stuttering whisper for use under conditions of extreme distress, when a good strong voice for both ordinary and distress conditions is easily obtainable. Vessels are said to sail as long as five days in some parts of the ocean without being able to carry on communication because of the great average distance of ships and small radio range.

I have endeavored to bring these points to the attention of all concerned, and have continually described the kind of apparatus I believe should be used. For a time I tried to explain verbally what I believed could be reasonably obtained at the present time.

A little more than a year ago, I put my ideas of what should be used as radio equipment on board vessels into the form of a set of specifications, and in June, 1913, a number of these specifications were struck off. And it is these revised specifications, with some slight modifications and explanations, that I am presenting to-night for your discussion. In making these specifications, I tried to put myself in the position of steamship owners who desired to secure as satisfactory equipment as could be obtained at a reasonable price at the present point in radio development; and to make the specifications such that when

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sent out to all manufacturers of radio apparatus, apparatus conforming to the present status of radio development would be offered. This practice of sending out specifications has been adopted by the United States Navy to a considerable extent; and it is probably due to this, in a general way, that we have quite high class radio apparatus manufactured in the United States. Should this practice be followed by the steamship companies, it would probably result in still further development. It certainly would result in the steamship companies obtaining far better apparatus than they have at present. In making up these specifications the United States Navy 16 R 1 specifications were used partly as a guide.

The apparatus described is similar to apparatus which has been furnished to the United States Navy, but in this case it is considered to be manufactured in large quantities; thus making it very much less expensive. Probably 75 per cent. of the past cost of such apparatus has been due to the very small quantity manufactured at a time, to new features developed each time, and to inefficient factory methods. That is, the apparatus produced would probably be classified as "special apparatus," inefficiently manufactured.

The following specifications call for apparatus which, to a large extent, is not special; because the various designers of similar apparatus know how it can be made without further designs or cut-and-try methods, and the quantity (125 sets) makes it possible to have the order filled by an efficient manufacturing firm.

The proposition is not idealistic in an impractical sense. With but one or two minor exceptions it only calls for what has been manufactured, tried, and is in use. It is simply a proposition to replace known poor apparatus by known better apparatus.

There is at least one group of steamship companies that control together about 125 vessels, and this group could arrange to order the same kind of apparatus at the same time (i. e., 125 sets); and thus obtain good apparatus at lower cost.

As to patents, there are said to be ways of avoiding infringement of them in cases in which the courts have rendered decisions. Furthermore, some unfavorable decisions may be reversed, and some of the patents expire before long.

## SPECIFICATIONS FOR RADIO EQUIPMENT.

1. The purpose of this specification is to obtain steamship radio equipment, with which ample, correct, and prompt radio

service may be maintained, under normal and distress conditions, with provisions for emergency-lighting power.

2. Bids are to include detailed specifications (in English), photographs, drawings, and diagrams; delivery and price.

3. It is desired that the bids be received at this office prior to ......... Bids received after that date may or may not be considered.

4. Simplicity and good workmanship, without expensive construction or ornamentation, are desired. (This is an effective method of keeping down cost.)

5. All work to be done to drawings, templates, jigs and gauges, in order that strict interchangeability be insured for all parts, both fixed and moving.

6. All parts to be exposed to view, simple, compact and accessible, so far as practicable. (I find that the practice of hiding cheap and inefficient parts in handsome and expensive cases is somewhat general, and should be discouraged.)

7. Apparatus to retain its efficiency, power and appearance, with minimum cleaning, under the atmospheric conditions between the latitudes 45° North and 45° South during all seasons of the year.

8. All parts and units which cannot be easily and quickly repaired with material commonly available on shipboard, and which are liable to need repairs, and are essential to the use of the station, are to be furnished in duplicate (or in such quantities as will insure the continuous working of the station between ports where these parts are available). (Each set to include, at least, a spare armature, spare field coils, high tension condensers, telephones, and transformer secondary sections, or spare transformer if the windings are not removable.)

8A. As certainty of communication without delay is required under distress conditions, it may be found that a spare motor generator should be included.

Motor generators in the quantity these specifications would thus include (i. e. about 250), probably would be had for 250 dollars each from the maker.

9. Apparatus to produce as little noise and vibration as practicable, and not to get out of adjustment because of the ship's vibration.

10. So far as practicable, equipment to occupy as little table space as possible, and be arranged for installation on or above the operating table.

11. Other things being equal, self-contained sets, requiring minimum installation labor, will be given preference.

12. Parts and units to be permanently marked or by name plate; with name, type, style, serial number, volts, amperes, watts, cycles, resistance, inductance capacity, r.p.m., etc., according to the best practice.

13. In so far as practicable, all high-tension insulators are to be of glazed wet process porcelain, low tension insulation, according to New York Board of Underwriters' rules; and the receiver insulation is to be of hard rubber. The insulation is to receive special attention, and to be tested for fatigue, and resistance to moisture.

14. All mechanical supports to be, in so far as practicable, of metal not materially affected by atmospheric conditions.

15. Radio frequency conductors, as a rule, to be of copper or triple-plated with silver.

16. All contacts, both fixed and variable, to have a resistance of less than 0.01 ohm, and to work without sparking or heating, and with minimum mechanical and electrical deterioration.

17. Contacts to be soldered where practicable, using non-corrosive soldering flux.

18. Instruments to be capable of indicating 25 per cent. higher than it is expected it will be necessary for them to indicate.

19. Each equipment to include a cabinet, with hinged door, and locks with two keys, containing all tools necessary for maintenance of the equipment, and a bound book of typewritten or printed instructions, with drawings and diagrams showing the construction of the equipment in full detail and methods for locating and repairing faults. Cabinet to be arranged for fastening to the wall. The door of the cabinet to be partly of glass, arranged to hold the operator's licenses in such a way that they may be read thru the glass.

20. Auxiliary equipment is to include an auxiliary source of power (Edison storage battery), independent of the ship's main power, capable of supplying the transmitter for six hours' continuous sending using Continental Morse at full rated power. Also the necessary fuses, under-load circuit breakers, resistances, switches, etc., necessary properly to charge the battery from the ship's mains at any line voltage, from 90 to 120 volts, these to be mounted on the switchboard. Also trays, distilled water tank, filling device and hydrometer. Separate bids may be made on storage cell compartment, suitable for installation in

the operating room. In addition to supplying the transmitter for six hours' continuous sending, the storage battery is to be capable of supplying 500 watts for six hours, for l ghting purposes.

20A. The Edison storage battery is specified because the Edison battery seems to be so far beyond any other auxiliary for this purpose that it should be named specifically.

The right kind of auxiliary is one which can be brought into service immediately and which will give at least as much power and range as could be obtained by the use of power from the engine room; that is, the ship should be able to send as far in times of distress as under ordinary conditions (or farther). For this purpose, I have considered a number of kinds of auxiliary power which are mentioned briefly:

1. STEAM ENGINE.

For a steam engine to be ready for immediate service would require the proper working steam pressure at all times whether or not there was a fire under the main boiler. To install a steam engine in a location such that the operator could start it quickly and not be interfered with by its noise, is a problem.

2. GASOLINE ENGINE.

These are commonly considered as uncertain as to the time required to start them, and they usually make considerable noise. Also, the present law does not permit carrying of gasoline on board steamships.

3. OIL ENGINE.

These have a reputation of being more or less uncertain as to the time required to start them. Furthermore, they make some noise, and it is a question as to where they should be located so as to be readily accessible in an emergency.

4. MANUALLY DRIVEN GENERATORS.

Generators with crank gear to be turned by members of the crew have been suggested, but generators which would furnish sufficient power would probably require a number of people to turn them and considerable space for these people; and it is quite possible that members of the crew might not be obtainable or controllable in times of distress.

5. STORAGE BATTERIES.

Storage batteries make very little noise, practically none, because they can be installed in cabinets which will muffle what

little noise they do make. These cabinets can be in the operating room, ventilated to the outside. Or possibly, in some cases, they might be just outside the operating room. They can be brought into use in less than a second by providing a double throw switch which, when simply thrown from one position to the other, disconnects the engine room leads and connects the storage battery leads. Any form of storage battery is probably far more desirable than any present form of engine. However, lead storage batteries have a number of drawbacks. Some of the objections to lead storage batteries are as follows:

## LEAD STORAGE BATTERIES.

First. The acid they contain, if spilled, which is frequently the case, is injurious to other apparatus, and furnishings. The gases from a lead battery are detrimental to certain materials. For instance, ropes on life boat davits are rotted thereby. This occurred on a United States warship recently.

Second. They may be seriously damaged by over-discharging, over-charging, evaporation of electrolyte, use of impure water or of salt water.

Third. They require continuous careful attention on the part of operators and inspectors. The attention they receive from operators is uncertain and varies as the operators change.

Fourth. Their condition (that is, as to how long they will operate) is usually something which it takes considerable time for the inspector to determine.

Fifth. Even when reasonably well cared for, their length of life at the rated output is not very great. If a lead battery is placed on a rocking base, the plates may be broken, and the separators damaged. The active material is particularly likely to be jarred out of place, or washed out by the splashing electrolyte.

## EDISON STORAGE BATTERIES. (IRON AND NICKEL.)

The Edison storage battery is apparently quite different from lead storage batteries mainly in that it seems to be practically fool-proof. When I first read the Edison storage battery literature, I doubted some of their statements, but later investigations, which have now lasted over a period of about two years, have lead me to believe that their claims are true; and if anything, that they have underrated their battery (particularly in the matter of ampere-hour capacity when it is applied to this auxiliary use). I have repeatedly tested a battery of 100 Edison cells. By courtesy of the College of the City of New York and Dr. A. N. Goldsmith, these cells were installed

in the Radio Laboratory of the College of the City of New York, and a number of tests have been made on them during the past year.

Practically the only argument that has been advanced against the Edison battery is that its efficiency for individual charge and discharge is not as high as that of the lead cells. That is, for a given number of ampere hours supplied to a *new* lead cell or an Edison battery, more ampere hours can be gotten out of the lead cell. However, it is recommended that the lead cell be charged and discharged at least once every two weeks to keep it in good condition. This is a serious waste of power and attention. The Edison cell can be left standing indefinitely without attention. Moreover, lack of efficiency is negligible for the purpose of an auxiliary source of power for radio apparatus because for that purpose the battery is so seldom used that its watt-hour efficiency is not material. According to the rules the battery is for use only in times of emergency.

The Edison battery costs more than the lead battery but it undoubtedly will last very much longer and cost less for maintenance; and it is claimed that in the long run the Edison battery would be found to cost *less*. The auxiliary source of power will probably never be satisfactory and will cause the steamship companies more or less trouble until that auxiliary source of power conforms to the fundamentals; namely, *full power*, *instant service* and *reliability*, and I believe the Edison storage battery properly installed meets these fundamental requirements. In August, 1910, a set of Edison batteries were put into quite steady service at the Brooklyn Navy Yard, and they are still completely satisfactory, I am told.

21. Transmitter. All apparatus used in transforming the energy drawn from the ship's mains or storage battery into radio energy in the antenna.

(This is so worded as to include blowers, motors, resistance, etc., which may be necessary adjuncts to the radio transmitter.)

22. Rating of transmitters to be in terms of the energy developed in the antenna (watts in the antenna). Efficiency to be in terms of the ratio of energy in the antenna to the energy drawn from the ship's mains or storage battery by the transmitter.

(At present the rating of commercial transmitters is, to say the least, chaotic. Some of them are rated in terms of watts in the primary of the transformer, but some apparently must have been rated in terms of the energy in the engine driving

the ship's dynamo, or possibly in terms of the energy in the coal bunker.)

23. Tests for rating to be made on an approved artificial antenna, having a capacity of 0.001 microfarads (compressed air dielectric), inductance of 40 microhenrys and resistance of 6 ohms.

24. The energy in the artificial antenna to be at least 1200 watts on all wave lengths from 450 to 600 meters, and as much energy as practicable from 300 to 450 meters.

(It is thought that if the manufacturers' experts can get 1200 watts in the artificial antenna, the operators will be able to get about 1 kilowatt in the antenna a greater part of the time.)

25. The transmitting circuit supplied with each set when adjusted to the artificial antenna shall be capable of continuous six-hour telegraphic operation, without any sparking, breakdown or injurious strain on any part of the apparatus, at the full rated output thruout the entire range of wave lengths.

26. The transmitting power required from engine room or storage battery is not to exceed 3 kilowatts.

27. Transmitting couplers to be calibrated for coupling and wave lengths. At least one of the coupler circuits to be calibrated in wave lengths. Couplings and wave lengths to be continuously variable between 300 and 600 meters.

28. Transmitter to be so arranged that the operator can conveniently change to any one of four wave lengths between 300 and 600 meters in 10 seconds, antenna energy to be within 25 per cent. of full power as rated for that wave length.

29. Other things being equal, constructions in which the exciting and radiating circuits can be simultaneously and rapidly adjusted to any wave length within the required range, without requiring the operator to leave his seat, are desired.

30. Transmitters to be capable also of sending on wave lengths from 1,600 to at least 2,000 meters on antennae having a capacity of 0.0007 microfarads, and inductance of 55 microhenrys.

31. Each transmitter to include a suitable adjustable capacity, to be used in series with antenna, to bring the wave length down to 300 meters, where the antenna may have any capacity between 0.0007 and 0.0025 microfarads.

32. All transmitters to be capable of giving pure notes at any sound frequency from 800 to 1,200 periods. Of these transmitters, 50 to radiate maximum power at 800 periods per second (sound frequency), 25 to radiate maximum power at 1,000

periods per second (sound frequency), 50 to radiate maximum power at 1,200 periods per second (sound frequency).

Should the total amount be between 100 and 125 sets, the decrease is to be made from the 25 sets.

32A. As 125 ships is probably the largest number under the American flag that is controlled by one group of steamship interest, this number is used in these specifications. In order to get such equipment as is herein specified at not too great a cost it is probably necessary that the equipments be manufactured in quantities of 25 or more. In such quantities the work should be an excellent manufacturing proposition. The set that will put 1,200 watts in the antenna should cost but a small percentage more than one that will put 600 watts in the antenna, because the development charges and overhead cost should be about the same for a quantity of 1,200 watt transmitters as for 600 watt transmitters, and no additional patent charges should be made for the 1,200 watts size as the same patents apply for either size.

Different audio frequencies are specified to provide against interference due to similarity of sound and also to permit of audio or group tuning.

33. The design shall be such that the adjustments for obtaining a uniformly clear, pure, musical note shall not be critical, but of wide range.

34. Transmitters to radiate at least 95 per cent. of the energy in a single wave having a logarithmic decrement of less than 0.2 under all required conditions.

35. Transmitters to give full rated power and efficiency when supplied with current from the ship's mains or storage battery, at any voltage between 90 and 130.

36. Transmitter to make as little noise as is practicable with a quenched gap transmitter. Other things being equal, a muffler around the condenser may be desirable.

37. The energy in the antenna to be easi y variable in at least five steps from the rated energy to 50 watts, preferably with a corresponding decrease in the input from the ship's mains or storage battery. Minimum transformer input not to exceed 500 watts.

(I have said 1,200 watts in the antenna as shown by trial test. This sounds large but I do not believe it is too large when we consider that we should have a factor of safety. Firstly, I believe operators seldom have the transmitter in proper adjustment to give full power; secondly, transmitters may depreciate

so as to reduce the power radiated; thirdly, even 1,200 watts may not work 100 miles when atmospherics are strong; fourthly, ranges may vary even irrespective of atmospherics.

A power of 1,200 watts, or even 600 watts, on a winter night would probably cause interference over a distance far greater than it is desired to send. Therefore it is desirable that the operator cut down the radiated energy at such times and this should be made easy so that he will not neglect to do it. Loosening the transmitter coupling is probably the easiest and quickest way. For example, one coupler coil may be hinged so that it may be easily swung at right angles to the other.)

38. Low tension control devices and instruments, except the transmitting key, receiving controls, and push button for motor starter, to be mounted on the switchboard.

39. Transmitting instruments to include D. C. volt and ammeter for use in the line and storage battery circuits, A. C. volt and ammeter for the dynamo circuit, and ammeter for the antenna circuit.

40. Low tension power wiring to be encased in grounded metal covering; covering preferably mechanically stronger than lead; e. g. lead covered wire in conduits.

41. The motor starter to be arranged for automatically starting and stopping from push button control at the operating table.

42. The switchboard panel to be black, enameled, polished slate, well adapted for electrical purposes, at least one inch thick, with braced brackets for properly supporting the switchboard from the wall, so that the rear of the board will be accessible. At the bottom of the switchboard, on the rear side, shall be a line or lines of labelled terminals for attachment of all circuits leading to or from the board.

43. Dynamo potential is not to exceed 250 volts.

44. Motor and generator leads to be connected to the frame of the machine through protective mica condensers fastened to the frame.

45. As nearly as possible, the key should be as small and easy to operate as a Western Union key.

46. No energy to be drawn from the alternator when the key is open.

47. A cord and plug arrangement to be provided, for connecting the antenna directly to the ground at the room end of the roof insulator.

48. It is *not* intended that these specifications shall include only such apparatus as that wherein received sound frequency is controlled by the transmitter. Should the transmitters offered be of such type that waves of constant amplitude are radiated, the transmitter is to be provided with an interrupting device for conductively or inductively varying the energy according to the sound frequencies specified, so the signals may be read on the types of receivers now commonly in use. With bids on constant amplitude transmitters, receivers must be provided that will enable the operator to receive satisfactorily at will, either constant amplitude waves or those of periodically varying amplitude. Also an automatic receiver to be provided, arranged to operate alternately one-half the time in receiving each of the two mentioned types of radio energy.

49. Receivers. All the apparatus used in connection with the antenna to transform electromagnetic wave energy into sound energy, or energy in other forms, that can be used to render the signals intelligible.

50. The tuner to have a sharp tuning arrangement and broader tuning arrangements, with spring motor for continuously varying the wave length between 300 and 600 meters, at any rate from 10 seconds to 1 minute. The automatic device constructed to be quickly disconnected and the tuning done by hand. Motor to require as infrequent winding as practicable, and to be arranged to stop at 600 meters when nearly run down (by increasing friction at 600 meter point, or equally inexpensive means).

51. Receiver to have at least one adjustment by which any wave length from 300 to 600 meters is indicated in wave lengths in a scale.

52. Receivers to be capable of receiving from 200 to *3,000* meters on an antenna having a natural period of 380 meters.

53. Two detectors to be supplied, one as sensitive as the best "Perikon," and the other as stable and sensitive as the best carborundum.

54. Receiver to be fitted with binding-posts for a separate additional detector.

55. Receiver circuits to have a minimum effective radio frequency resistance.

56. Variable condensers in the receiver circuits to be of the air dielectric type, balanced.

57. The headgear to consist of two sensitive watch-case telephone receivers, mounted by universal joints on adjustable

insulated metal straps, and arranged so as to be adjustable and conveniently held on the head of the operator.

58. ANTENNA. Includes hoisting rope, spreaders, insulators, guys, wires, fittings, ground connector, and antenna switch for connecting to either the transmitter or receiver, and controlling circuits in each.

58A. The antenna should be counter-weighted, if possible, at the free end to prevent breakage. A great deal of breakage occurs in time of heavy wind and sleet.

59. Two 16 foot steel spreaders, protected against oxidation, and of minimum practicable weight, 2,000 feet of 13 strand, Number 18, phosphor or silicon bronze antenna wire, 200 feet of one-half inch phosphor bronze running rope, and adequate fittings, deck and strain insulators to be supplied with each set, on the basis of a six wire antenna.

59A. A single one-half inch diameter phosphor bronze cable arranged like a jumper stay between the masts, with proper porcelain, egg insulators at the mast ends, might be more desirable than the present form of antenna; that is, the reliability of such an arrangement might more than counterbalance its possible inferior sending and receiving qualities. Furthermore, on large vessels, where the present multiple wire antenna cannot be used in the L form for the full length between the masts on account of the necessity of using wave lengths as short as 300 meters, this single one-half inch cable in the L form extending full length between the masts might be even as good for sending and receiving as the multiple wire antenna, and have the added advantage of being more reliable in times of wind or sleet.

60. Antenna lead terminals to make good contact at the roof insulators connection, and to be easily removable from that connection, as may be required in handling cargo.

61. Antenna insulation, preferably of porcelain, so constructed that the antenna shall not fall due to breaking of the insulation; and that no piece of dangerous weight will fall in any case.

62. Insulation to be capable of insulating with a large factor of safety, *when subjected to salt water spray.*

63. Antenna switch to be arranged for ease and rapidity of operation, and to withstand hard usage.

64. Bids including prices and delivery time on 125 equipments are desired in any or all of the following ways. Prices to be F. O. B. (i. e. delivered at) docks. Also bids for 100 equipments, instead of 125, are desired.

A. Sale price 100 and 125 sets complete.

B. Sale price 100 and 125 sets complete, except storage battery. In this case, the steamship company will purchase its own batteries.

C. Sale price 100 and 125 sets complete, with maintenance, with and without storage battery.

D. Sale price 100 and 125 sets complete, without auxiliary, and with and without maintenance. In this case, the operation and maintenance will be entirely in the hands of the steamship company.

E. Sale price 100 and 125 quenched gap sets complete, except without auxiliary, motor generator and switchboard. Bidder to state the characteristics of the generator required. The steamship company will furnish its own generator; that is, it will supply alternating current and proper means for its control.

F. Rental prices per year per set for 100 and 125 sets, as in A, B, C and D. All the arrangements outlined above but on a rental basis.

G. Same as F, and including two first grade operators per set.

H. Same as G, except the contractor to take all tolls, and steamship business to be handled free of charge.

Bids according to A, B, and E to include at separate price, sufficient additional parts or units for port stock, to keep the 125 equipments offered in proper repair for one year, and an itemized price list of units and parts. Same for F and D, where maintenance is not included.

These different classifications of bids are suggested so that bids may be sent from all the various manufacturers of apparatus, regardless of whether or not they only manufacture and sell, or manufacture and rent, or manufacture, rent and operate.

Separate prices are desired on the following additional equipment:

125 automatic tape recorders, to be operated by the primary circuit of the transmitter, each in a case, with lock, for the purpose of providing a printed record of messages transmitted.

125 break key arrangements, with receiver protection, for use with transmitters offered.

3 Decremeters, arranged for wave length and decrement measurement, with range approximately 150 to 2,400 meters.

3 portable watt-meters, range 0 to 5 kilowatts for use on potentials from 80 to 300 volts.

3 portable radio frequency ammeters, correct on frequencies from 120,000 to 1,200,000 cycles, range 0 to 20 amperes per second.

3 portable frequency meters, range 450 to 650 cycles per second.

3 portable low-reading D. C. voltmeters, range 0 to 3 volts.

Artificial antenna and complete testing instruments to be provided by the contractor. Laboratory tests to be made by a representative of the purchaser using instruments of the contractor, or such instruments and apparatus as the purchaser may desire to use.

Each equipment to be subject to at least thirty days' operating trial before acceptance.

In the event of purchase, the contractor shall protect, defend and save harmless the purchaser against any demand for patent fees, or other claims of any description for any patented invention, article or arrangement that may be used in construction, or form any part of the articles delivered under the contract or the methods necessitated by their use.

**SUMMARY.** The author calls attention to certain serious defects in most existing radio ship equipment. He considers that the best possible radio equipment would be obtained by the steamship companies thru collective purchasing on a large scale of well-built apparatus constructed to meet standard specifications. He then supplies a complete set of proposed specifications for the construction of transmitter, auxiliary storage battery, receiver, antenna, and auxiliary parts.

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## DISCUSSION.

**Guy Hill:** Mr. Marriott has certainly covered the whole case and considered everything very completely, and there is very little which has not been touched upon. Some of the specifications, I do not think I would personally quite agree with, particularly in regard to insulating materials. For instance, I cannot approve the specification of hard rubber for receivers. I do not think that insulation should be limited to definite materials in this way, as some insulating materials on the market are, I think, far superior to hard rubber. Hard rubber has a tendency to deteriorate, especially near salt water. I believe the Navy has had trouble with hard rubber, as rubber parts of sets have shrunk. Another doubtful matter is the specification of porcelain for antenna insulation. This is unnecessary, as the Navy has used various other materials satisfactorily. The Navy, as a whole, has practically eliminated all porcelain insulation. I know a great deal of trouble has been experienced

by the porcelain breaking during handling and shipping, and we are now making insulating materials which are much stronger and harder, and give much greater satisfaction on the whole. I have not seen Mr. Marriott's paper before this evening, when it was read, and he has covered so much ground that it is hard to remember all his statements and discuss them off-hand.

As to spare parts which are to be furnished, their choice should be very carefully covered and mentioned in detail, as otherwise it would be quite hard to compare prices of the different companies. Sometimes the spare parts are one of the large items on a bid, and if the nature of these parts is not quite accurately stated, quite some trouble will be caused. The generator voltage, I might say, should be not more than 250 volts on open circuit and with the transmitter key raised, so that when the load is suddenly removed, the highest voltage with which the operator can come in contact, is not dangerously high. The replacing of fuses thereby becomes safe.

Storage batteries require further consideration. Mr. Marriott seems to be very enthusiastic concerning the Edison battery. A great many of the statements he gives are true. Lately, I have not followed the automobile industry very closely, but I know that in the past the automobile manufacturers, in developing their self-starting and lighting systems to meet the severe conditions met with service, have uniformly preferred the lead cells to the Edison batteries. Practically all of the people that investigated storage batteries for self-starters were opposed to Edison batteries and used the lead battery; and I think it might not be a bad idea to get more data from these companies as to their reasons for being opposed to the Edison battery, and favoring the lead batteries instead. Mr. Marriott should be congratulated on the great amount of work he has evidently done in this direction and the excellent specifications he has brought out.

**John Stone Stone:** I agree with Mr. Hill that it is very difficult to discuss a paper after having heard it only once, particularly when it has taken a year or more of study and construction to draw up the material contained therein. I am also in complete accord with Mr. Hill as regards hard rubber. The term "hard rubber" has not a very definite meaning, for it depends entirely on what kinds of material are purchased as to the amount of rubber present. There is only one further point I desire to mention and that is the omission of the method of

changing the type of transmitter when passing from the main set to the emergency set.

**Robert H. Marriott:** The same transmitters are to be used in each case.

**John Stone Stone:** Using the same power?

**Robert H. Marriott:** Using full power as before.

**John Stone Stone:** Is it not possible to employ a lower spark frequency for emergency transmission, thereby running the motor generator at lower speed and putting less strain on the storage batteries? A smaller storage battery could be used under such conditions. A slower rate of sending dots and dashes might partly compensate for the decreased power. The energy per spark might also be slightly increased.

**Robert H. Marriott:** The reason for using a high spark frequency is to be able to read the signals thru static, because the high pitched note "cuts thru" atmospheric noises.

**John Stone Stone:** It might be possible to overcome the bad effect on the range of a lower pitched note by putting more energy into each spark, and thereby keeping the range nearly constant.

**Robert H. Marriott:** If the atmospherics are strong enough, they will blot out the low spark signals of almost any intensity.

**John Stone Stone:** Even with very small sets at low spark frequencies, very great ranges have been obtained.

**Robert H. Marriott:** This is the case in the winter time but not in the summer; and emergency apparatus should be suitable for all year round work.

**A. F. Parkhurst:** In your discussions you have just mentioned the problem of furnishing emergency and auxiliary service.

We have met this service by the use of an auxiliary source of power; the storage battery.

No one can appreciate as much as we steamship men the necessity for some recognized specifications for Radio Equipments, such as those just proposed by Mr. Marriott.

All of our installations have been made with the end in view of having the most efficient service possible, especially under

emergency conditions. In fact, no expense has been spared in supplying every known emergency equipment on our vessels for promoting their safety and that of the passengers.

These precautions comply in both spirit and letter with all compulsory regulations. Naturally it has taken an enormous amount of time and detail, in addition to the expenditure of considerable sums of money, to perfect our radio service and bring it up to its acknowledged high standard of efficiency.

We, however, feel repaid by this one fact: while not being exempt from accidents, we have yet to suffer the loss of a member of our fleet.

After a number of years of experience we have arrived at what we believe to be the ideal specifications for steamship radio equipment in our very exacting service.

These specifications differ but slightly from those contained in the paper presented by Mr. Marriott this evening. I therefore feel in a position to present conclusive argument which should tend towards the adoption of specifications such as these by all steamship lines.

This would naturally be somewhat lengthy. I will therefore reserve further discussion for a paper which I propose to present to you at an early date.

**John L. Hogan, Jr.**: I did not have an opportunity to read Mr. Marriott's paper before this evening, but, in talking over the matter with some of the National Electric Signaling Company's engineers after the announcement of the subject of the paper, we reached the conclusion that it might interest the members of the Institute to learn of the views and methods of our Company in attacking the problem of emergency and auxiliary service.

We have made a number of transmission tests, and as the result of our experience are convinced that 100 miles cannot be covered under ordinary conditions (or possibly under conditions slightly worse than ordinary) when using less than 250 watts in the primary of the power transformer of an efficient transmitter. The sets which Mr. Marriott has described and those which the United Fruit Company has used, are, no doubt, nearly ideal. Unfortunately (or, from another viewpoint, fortunately), the present law does not require anything like the technical perfection and expense which the specifications of Mr. Marriott would demand. The steamship companies, in general, practice the strictest economy in the matter of radio

equipment. They do not seem willing to consider radio service a profitable form of insurance and to balance its small expense against the value of ships and cargoes, loss of which is frequently prevented by even poorly efficient service, nor to credit the stimulating effect of good radio service upon passenger traffic.

In view of this attitude, a compromise between the ideal and the cheapest is required, and to secure a desirable outfit at reasonable cost we must eliminate all but essentials. It is evident that the parts of the radio transmitter which most frequently break down must be supplied in duplicate, if service is to be maintained. We have reached much the same conclusion as has Mr. Marriott as to which parts least stand the strain of service, and believe that the weakness of the set is concentrated at five points, namely:

1. The power source.
2. The motor-generator.
3. The power transformer.
4. The condenser.
5. The spark gap.

These parts should be supplied in duplicate. We have found that the expense of duplicating the large motor-generator set which is used for ordinary transmission is excessive, and we have therefore adopted a complete and separate, but smaller, auxiliary motor-generator set for emergency use. For a 2 kilowatt main set we provide a motor-generator set of ½ kilowatt at 500 cycles for emergency use. As to the auxiliary power source, there is supplied an Edison or lead storage battery which is able to run either the main or the emergency set. If the storage battery is chosen to run the ½ kilowatt auxiliary set for four hours, it can be relied upon to operate the 2 kilowatt main set for half an hour. In this way, in times of distress, the operator can call for help and establish communication on the emergency set. If then static is too severe to permit easy transmission with ½ kilowatt power, he can send important data relative to his position and condition by using the high power set. Many other conditions under which it would be highly important to run the main set when the ship's power is cut off suggest themselves immediately.

The provision of the storage battery and the additional smaller motor-generator provides spares for the items numbered (1) and (2) above. In our sets a duplicate power transformer is furnished, as are spare condenser and gap units. In this way all parts of the transmitter which are subject to failure are

reinforced by spares, and we have available two complete radio frequency spark sets, one of 0.5 kilowatt and one of 2 kilowatts. Either of these may be operated from the ship's power or from the storage battery at will, simply by throwing two switches. The wiring is such that even under conditions of excitement the operator can make no mistake in connections.

I agree with Mr. Hill that the experience of the automobile manufacturers in connection with storage batteries for starting and lighting systems is highly pertinent, and think it is further evidence that lead cells may be used for severe service with satisfactory results. Referring again to Mr. Marriott's specifications, it seems to me that the range of the receiving sets should reach at least 3,000 meters wave length with the average ship's antenna. Time signals are now transmitted by the Navy on the standard wave length of 2,500 meters, and since these signals are of great importance to navigators the range of wave lengths of the receivers should include at least 2,600 meters, tho not necessarily at maximum efficiency.

**Alfred N. Goldsmith:** We cannot, without further tests, agree that the storage battery which will operate a ½ kilowatt set for two hours, under the usual conditions of radio service, will operate a 2 kilowatt set continually for one-half hour. If the storage battery is kept on a greater load, excessive polarization results, and the output of the battery diminishes rapidly. The battery is quite able to recover from this polarization, if sufficient time elapses. The extent to which this fact would affect Mr. Hogan's conclusions would have to be experimentally determined.

**John Stone Stone:** Is the time required for recovery of the battery not known?

**Alfred N. Goldsmith:** It may be at least 10 or 15 minutes, and it must be taken into account.

**Emil J. Simon:** The set which Mr. Marriott has outlined meets the engineering and operating requirements most fully, but it would hardly appeal to the average steamship company. It would be too expensive. Under ordinary circumstances, such a set with duplicate motor and generator and other spare parts as described, could not be purchased for less than $4,000. A storage battery equipment of sufficient capacity to operate such a set with full power for six hours will cost an additional $2,000. A set of one-half the capacity of that described by Mr. Marriott;

that is to say, a 1 kilowatt set, would be sufficient for maintaining communication up to several hundred miles under nearly all of the conditions met with by ships even in the tropics. I would like to hear from Mr. Parkhurst, as to whether in his opinion the 2 kilowatt sets which his company is using are not larger than necessary except under rare atmospheric conditions. I may say, in this connection, that with a modern quenched spark set supplying 350 watts to the transformer and delivering an antenna current of 6 amperes a daylight range of 300 miles (500 km.) in the tropics was easily attained in the summer time on a vessel of the United Fruit Company. I am certain that this range is not at all exceptional, and could be repeated at any time.

A set of the size specified by Mr. Marriott; namely, one delivering 1.2 kilowatts in the antenna, which corresponds to between 15 and 18 amperes antenna current, might well be considered unnecessarily large in a vessel of the Fruit Company type. I think it would be well for the Institute engineers to determine the proper amount of power which should be used to meet the legal requirements in order that no excessive burden or expense shall be placed on the steamship companies. I should value the opinions of the engineers present.

**John L. Hogan, Jr.:** Referring to the statements of Dr. Goldsmith, concerning the total time of discharge of the secondary cells under overload conditions, I would say that we have found it possible to choose a storage battery such that the ratios between power delivered and time of discharge which I have already given for our sets will hold good.

I agree with Mr. Simon that efficient 0.5 kilowatt 500 cycle sets are in general quite capable of meeting the legal requirements for auxiliary transmitters, with an ample factor of safety. In our design of ship apparatus, the smaller set meets all the usual requirements of service, yet the large set is always on hand in case exceptional conditions render its use, for a limited period of time, desirable or necessary. It may also be pointed out that on many ships the space economy effected makes this design of transmitter of far more value than one in which the large motor generator is duplicated and a large storage battery furnished.

**Alfred N. Goldsmith:** It is true that a storage battery can be chosen which will operate a 0.5 kilowatt set two hours continuously, or a 2.0 kilowatt set 0.5 hour continuously, but it must be a considerably larger battery than one meeting only

the first of these requirements. How much larger it must be, only experiments under service conditions can show. It will be noticed that no attempt at securing inverse proportionality between power delivered and time of discharge is made for the storage battery equipment Mr. Hogan describes.

**Robert H. Marriott:** As regards hard rubber, I believe that certain other compounds have recently proven more satisfactory. I cannot subscribe to the doubts concerning the Edison storage battery. If it is investigated, it will be found to speak for itself when compared to other auxiliary sources of power.

The equipment which I have specified is not to be regarded as ideal; it is better to call it "fairly up-to-date." Those steamship companies which desire complete radio service and protection will probably add further equipment, as, for example, a radio telephone outfit which will enable the captain, while standing on his bridge, to talk to the captains of other ships in foggy weather, or to get directions from the pilot boat. Radio equipment and service are entitled to more than they receive generally. The vessels having radio equipment are said to cost from $100,000 to $15,000,000 each, *without cargo.* It costs $300 per day to run a small vessel, and a vessel need not be very large to cost $3,000 per day. A consideration of these specifications and the quantities of apparatus required will indicate that the outfit, including the battery, could be supplied at a good profit for less than $3,000, and this possibly even in lots of 50 or less. Furthermore, it should be remembered that good equipment costs less to maintain and operate.

It is very necessary to have a reserve of plenty of power so as to be able to work thru summer atmospherics and absorption. Fog or fire may require an S. O. S. at noon in July as well as at midnight in February. I cannot overemphasize the importance of large factors of safety in radio equipment. When the radio equipment includes a battery it is a safety and emergency device. In designing it, the benefits of any doubt should be given to the passenger and ship, the existence of which may depend on the radio set.

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A motion was regularly made, seconded, and unanimously passed, that the thanks of the Institute be extended to Mr. Marriott for his useful and entertaining paper.

At the suggestion of Mr. Hill, a motion to appoint a committee on Standard Minimum Radio Specifications was placed before the Institute. It was carried, and Chairman Stone announced that he would later (he having been designated as the appointing official by the Institute) appoint the Committee. It was understood that the Committee was to restrict itself to the formulation of minimum requirements so worded as to indicate definitely that further progress and increased rigidity of specifications were completely possible, and even imminent.

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## CONTENTS

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# THE RADIO OPERATOR PROBLEM.*

By

V. Ford Greaves,

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It has been my good fortune during the past few years to hear some excellent papers read on radio engineering subjects, and the allied arts, by prominent engineers and scientists of a professional standing recognized here and abroad. I have always been particularly interested in the discussions and I am convinced that no matter what the subject, who the author, nor how convincing the conclusions, there is usually to be found in the audience an honest difference of opinion on at least one point and sometimes several. In this lies the value of these meetings. Then, too, in this day and age of trained minds, the specialist often receives valuable hints and suggestions from interested workers in other lines.

This leads to the question, "What is an exact science, and when may one be justified in making a positive statement?" Surely arithmetic may be so classed, altho there may be doubt as to the status of some of the branches of higher mathematics as applied to the arts and sciences. We regret that at present medicine and surgery are not exact sciences.

The art of "Radio Communication" is comparatively new. Convinced by the marked consistency and steady agreements of researches conducted in this field during the past few years, I believe we are all satisfied that a certain portion of radio engineering, at least, may be classified under the heading of an "exact science."

Radio engineering as a whole may not be termed an "exact science" so long as the radio operating element enters as such an important factor. This thought occurred to me repeatedly on hearing eminent radio experts lament operating difficulties.

There are several phases of the operator problem. Three of the most important of these are proficiency in the use of the

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code, skill in the care and adjustment of the apparatus, and reliability in an emergency.

The requirements of the Naval Radio Service are, of course, most exacting. They include speed in operating, a knowledge of comparatively complicated apparatus, and personal reliability under severe circumstances, including the possibility of disaster in time of peace and of operating under fire in time of war.

Commercial operators are not as a rule required to change their wave lengths nor to make adjustments. A corps of engineers, inspectors and repairmen are maintained at important ports to make necessary adjustments and repairs. However, a certain knowledge of the connections and adjustment is very important and the law requires commercial operators to have this knowledge.

To the extent that "Safety at Sea" depends upon the radio operator, speed is not particularly important, altho it may be desirable under certain circumstances. All operators, of course, can send and receive slowly. To the commercial companies, so far as traffic is concerned, speed is the essential consideration.

The Signal Corps of the Army, the Revenue Cutter Service, and a few other Government departments employing radio operators have certain other special requirements.

Therefore, several phases of the operator problem must be studied. These are operating speed; knowledge of the care and adjustment of the apparatus; and dependability. Possibly we must consider also such a knowledge of the traffic laws and regulations as is essential to reduce interference.

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My connection with the Bureau of Navigation has given me an excellent opportunity to study the problem, as I have had several hundred operators' examination papers available from which to draw conclusions and to estimate averages.

## OPERATING SPEED.

Let us first consider the question of operating speed.

I am fully satisfied, and I believe experienced inspectors will agree with me, that speed in operating is somewhat of a talent. It is a much more simple engineering problem to force oscillations in a circuit than to force an ungifted individual thru an operator's training school.

We are all more or less familiar with the comparatively simple duties of the "land line operator," which simplicity

probably accounts for the excess of average speed of land line transmission as compared to radio transmission.

The land line operator has to deal with very simple apparatus requiring little or no adjustment. He does not have interference to contend with, nor faint and variable signals. The "spark frequency" produced by a "sounder" is the same for all instruments and under all conditions—and, in this country, he uses American Morse code.

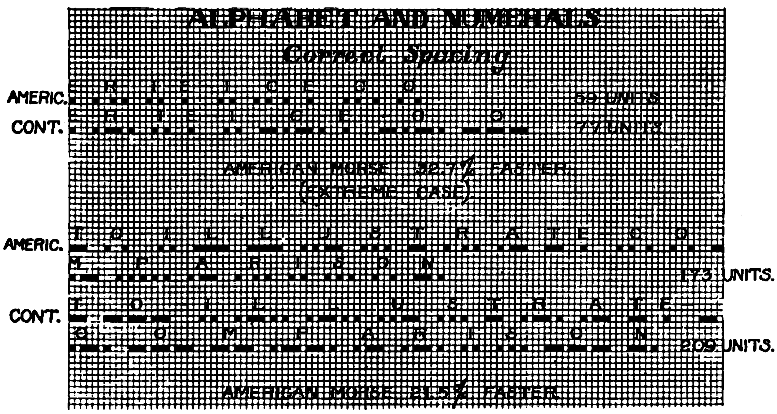



Figure 1

As regards the American Morse code, I may state that I am a strong champion of the American Morse code for radio work, altho I am compelled to bow to the overwhelming majority in favor of the Continental Morse. The necessity for a universal radio code is, of course, apparent to all.

However, a few comparisons that I have made between the two codes may be of interest.

TABLE.

CONTINENTAL MORSE.

One dot is the unit of time.
A dash is equal to three dots.
The space between parts of the same letter is equal to one dot.
The space between two letters is equal to three dots.
The space between two words is equal to five dots.

AMERICAN MORSE.

The space in spaced letters is equal to two dots.
The letter L is equal to two dashes.
Zero is equal to three dashes.

Hence, including the letters and numerals only, and allowing three units space between each letter:

American Morse = 394 dots (for the alphabet).

Continental Morse = 460 dots.

Therefore, as a whole, the American Morse is about 16.7 per cent. faster than Continental for the same degree of skill. In ordinary use it is probably about 20 per cent. faster. This is illustrated in Figure 1.

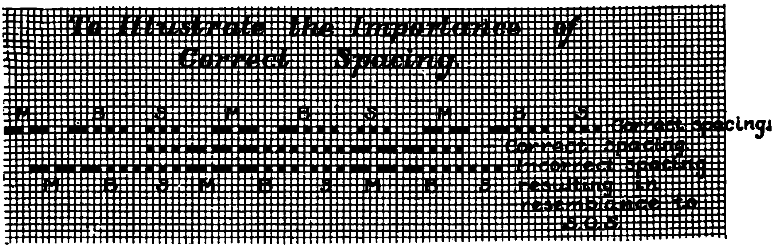



FIGURE 2

I believe the principal objection to the American code for radio purposes is the assumed possibility of confusion in the reception of the "spaced" letters, which may be caused by "static." To this objection, I do not agree. It seems to me that the chances are about equal of static making an "S" out of the American Morse "O"; or an "H" out of the American Morse "C," or an "R" and "S" out of the Continental "I"; etc. The same reasoning applies to static dashes. Compare Figure 2.

I have said that I believe good operating is something of a talent. If this be true, I may then be permitted to state my belief in the superior attractiveness of American Morse. To my mind, the American Morse code is more *artistic* than the Continental. It has more rhythm and seems to be more graceful and better balanced. However, I shall not press this point. The law provides for the use of the Continental code, and we are law abiding citizens.

Experience has shown that skilled land line operators make the best radio operators even when compelled to use the Continental code. Operators of shore stations are usually required to be familiar with both codes so as to operate both the radio apparatus and the land line connection. It is found that the land line operator acquires skill in the use of the Continental code as

used in radiotelegraphy much more readily than the radio operator can pick up the use of the sounder, altho the difficulty of the differences between the two codes are about equal, only eleven of the letters being different. This may be accounted for by the fact that a long "buzz" is a much clearer representation of a dash than the double click of a sounder.

It may appear at first thought that the examination of operators to determine their speed in receiving is a very simple matter and this is so if certain precautions are taken. We have often heard that skilled operators recognize each other by their "style" of sending (or "fist," which, I believe, is the operator's term). Some expert operators have told me that there is almost as much individuality to the "style" of sending as to handwriting. This can be shown in a few moments by means of the Omnigraph.

Such individual differences being existent, the examination of operators in code should not be conducted by means of hand sending if consistency and uniformity are important.

Some claim that an operator, to be entitled to a license, should be able to receive the sort of erratic sending which he may encounter in practice and that the test should be conducted by hand. But such a rule is too flexible. An operator may time himself to send twenty words in one minute, but part of the time he may have sent at the rate of twenty-five words per minute and part at fifteen. With a view to uniformity and consistency at the several examining offices, the Bureau of Navigation adopted an automatic machine sender called the Omnigraph. The signals are cut on dials and the spacing is theoretically correct. The clock works are provided with a governor so that the speed may be maintained uniformly at the desired number of words per minute. Another adjustment is also provided which permits of a certain variation in the "style" of sending. We can thus supply the difference between the "short dot, jerky style" of the amateur and the "long dot, paralytic style" of the practised professional.

Some operators have objected to being examined by means of the Omnigraph; stating that whereas they could receive twenty words a minute if the sending were by hand, they could not copy signals from the Omnigraph at that speed. In one case it was found that the reason the operator could not read the Omnigraph signals was because of the confusing echoes, due to reverberation in the room of the sounds set up by the buzzer. The instrument was taken out of doors and the difficulty disappeared. This difficulty is easily obviated indoors by shunt-

ing a pair of telephones and condenser about a small resistance in the "buzzer circuit" as shown in Figure 3.

It seems to be advantageous to let the buzzer operate continuously, and to connect the Omnigraph in series with the telephone circuit.

Other complaints against the Omnigraph have been found to be due to more or less psychological reasons, such as nervousness and prejudice. Several experiments have been conducted with a view to eliminating complaints of this nature. The Omnigraph and a key have been mounted in one room and the telephone circuit extended into another. An expert operator has been employed to send by hand. By a switching device the

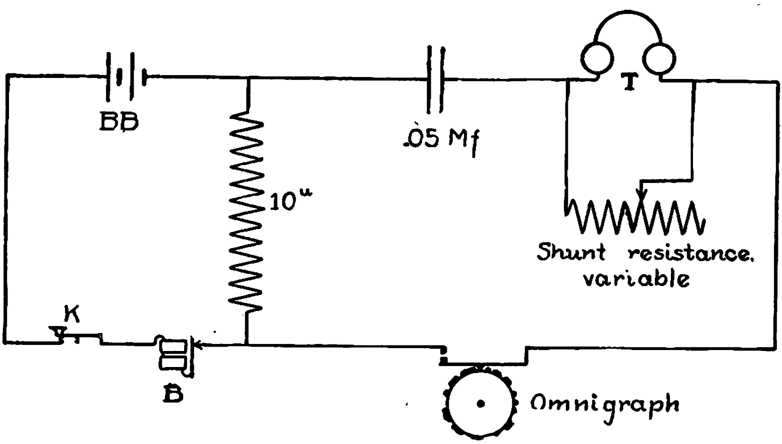



FIGURE 3

telephone circuit could be alternated between the Omnigraph and the hand key. In these experiments more than half of the operators who had previously objected to the Omnigraph stated that the Omnigraph was the better sender. The rest agreed that they could not tell the difference, and not in a single instance did an operator select the hand sending as the better. This experiment has been repeated several times in different parts of the country by different persons with practically the same results.

The Bureau of Navigation is therefore satisfied that the Omnigraph, or a similar machine, is very satisfactory and is fair to all as a means of conducting the code test.

The Bureau of Navigation General Letter No. 69, of April 10, 1914, provides:

"CONTINENTAL MORSE CODE TEST."

"The test shall consist of messages with call letters and regular preambles; conventional signals and abbreviations and odd phrases; and shall in no case consist of simple, connected reading matter. The test will be conducted by means of the omnigraph or other automatic instrument wherever possible.

"The test shall continue for five minutes at the speed of 20 words, 12 words and 5 words per minute, respectively, for commercial first, second, and lower grades, and to qualify, the applicant must receive correctly, 20, 12, or 5 words in consecutive order."

At 20 words per minute this is equivalent to giving an applicant five trials to make 100 per cent. in any one trial.

We will now pass on to a consideration of the technical knowledge desirable in a radio operator.

TECHNICAL KNOWLEDGE.

Examinations at best are unsatisfactory in many particulars. The desired aim may be accomplished on the average, but the injustice or excessive leniency sometimes shown are frequently very discouraging. Furthermore, the examiner usually feels that the examination he has prepared is too easy, and the operator usually complains that it is too hard.

In connection with the system of examinations of commercial radio operators for licenses, the Bureau of Navigation has received many compliments, complaints, criticisms and suggestions, all of which have been valuable. Some have suggested the elimination of any written examination; and advised depending upon oral questions and a practical demonstration to determine an applicant's qualifications.

This might be very successful if only one or two persons could conduct all the examinations, but where there are twenty or thirty persons conducting the examinations the personal element and individuality are found to vary to such a large extent as to render the suggested scheme impracticable even tho the desired results might be obtained by the two methods proposed. Furthermore, it is difficult to keep a record of oral and practical examinations and an exact record is valuable and necessary for later reference, in case of investigation or court proceedings.

Some have suggested that an applicant for commercial operator's license should be over 21 years of age; should have had a certain amount of practical experience at sea; should be examined physically as to hearing, etc.; should be considered as to his morals and submit evidence of good character; and

should be examined to determine "coolheadedness" and dependability in time of disaster or peril.

Some of these points are of course very difficult to determine, but granting that by some skilful method a man is found who qualifies in each, he is no longer a radio operator. He has been promoted from the operating rank to the position of installer, repair man, inspector, engineer or superintendent (commanding a salary anywhere from $1,000 to $5,000 per annum). We must bear in mind that the position of radio operator is the starting place in the practical field of radiotelegraphy.

The question of age I will discuss a little later. As to practical experience at sea, it is very difficult to see how the many hundred operators required can obtain it. A few schoolboys, of course, can arrange to take trips during the summer, on certain classes of vessels which are only required to have one first or second grade operator, but the young man who expects to depend upon operating for his living can hardly afford to make such trips on little or no pay.

As to dependability in time of disaster or peril, I do not believe this can be determined by any examination nor should the judgment of a keen observer of human character be relied upon; as personality enters to such an extent as to preclude even a fair degree of consistency.

In the Department of Commerce Regulations made pursuant to the radio laws, the stand is taken that so far as the law is concerned the qualifications of an operator can be determined by a code test and a written examination without oral questions or demonstration of adjustment of apparatus.

A company or individual employing a radio operator may be reasonably expected to determine special qualifications desired in an employee such as personal habits, morals, and whether or not he is subject to seasickness.

The present system of examination recently instituted at all the commercial radio operators' examining offices is based upon two years' experience with the problem. Many valuable suggestions from officers and experts of other Government Departments and Bureaus are incorporated. Lieutenant Commander Hepburn of the Navy Department and Mr. F. A. Kolster of the Bureau of Standards have been particularly interested in the problem. Their advice has proven extremely sound.

The examination is conducted under the following headings and values:—

| | | Points Maximum value. |
|---|---|---|
| 1. | Experience | 20 |
| 2. | Diagram of Receiving and Transmitting Apparatus | 10 |
| 3. | Knowledge of Transmitting Apparatus | 20 |
| 4. | Knowledge of Receiving Apparatus | 20 |
| 5. | Knowledge of Operation and Care of Storage Batteries | 10 |
| 6. | Knowledge of Motors and Generators | 10 |
| 7. | Knowledge of International Regulations Governing Radio Communication, and the United States Radio Laws and Regulations | 10 |
| | Total | 100 |

75 constitutes a passing mark for first-grade commercial.
65 constitutes a passing mark for second-grade commercial.

Experience operating either amateur apparatus or the apparatus provided in good operator training schools, or experience as apprentice at commercial shore stations and in ship stations is given an appropriate value.

The questions concerning the adjustments and functioning of the apparatus are intended to be so worded as to preclude the possibility of an undesirable applicant being especially primed for the examination. It is believed that the total number of questions so completely cover the whole field, so far as the operator is concerned, that there is little danger of applicants becoming familiar with the specific questions thru their frequent repetition. The questions are divided into several groups and an applicant cannot, of course, be especially primed for any one group.

I have heard complaints that some of the questions can be answered in a few words without developing the meaning of the answer if the applicant really understands his own answer. To a certain extent this cannot be helped. A question is more or less of a hint and an applicant is expected to state clearly his full knowledge of the subject. There is the further danger of long questions containing the answer.

(Some of the answers to questions which have come to my attention are amusing. For instance:—

Question: What is the effect of increasing the coupling? Answer. The coils are closer together.

Question: What are the advantages of the quenched spark gap? Answer. It is better. Etc.)

The theoretically ideal examination consists of one question, "What do you know about radio apparatus?", but such a question is, of course, not practicable.

The questions will, however, be revised from time to time. Applicants who fail to qualify will not be re-examined within three months. As there is no fee attached to the examination, it has been found that many incompetent operators try the examination frequently to see if they can accidentally pass. Others desire to become familiar with the system and questions. It is believed that the three months' clause in the regulations will thus eliminate a great deal of unnecessary work on the part of examining officers and result in applicants being more thoroly prepared before attempting the examination. The records show that under the old system only one applicant out of nine qualified. That is counting each examination of those who made several attempts to pass, many of whom finally procured licenses.

All examination papers, whether the applicant qualifies or not, are filed in the Bureau of Navigation in an individual record of the operator.

## AGE.

Several persons have suggested that the law should specify a minimum age limit for commercial radio operators, especially for shipboard work. Such a law might have certain advantages but would be difficult to enforce.

If, for instance, a minimum age of 18 were fixed, we all know that a great many excellent operators would be disqualified, and many undesirable candidates would not hesitate to overstate their age, even under oath. This latter statement is known to be a regrettable fact and is substantiated by statistics of services in which a minimum age is specified, even tho a severe penalty for false statement of age is provided. It is not practicable to search out birth certificates of several thousand men per year.

After all, so far as existing conditions are concerned, the question of age seems to have adjusted itself quite satisfactorily, and in this, as before, the person employing an operator may be expected to employ older men for the more responsible positions.

There are a few boys 15 years of age holding commercial first-grade licenses, but from a search of inspection records on file in the Bureau of Navigation it does not appear that any of these are employed at commercial stations or on ships as senior operators.

We give herewith a chart and a curve showing the ages of licensed operators, commercial first and second grades.

Figure 4

DEPARTMENT OF COMMERCE,

*Bureau of Navigation, Radio Service.*
Washington, February 28, 1914.

COMMERCIAL WIRELESS OPERATORS.

The following tables show the number of commercial radio operators and their ages at the time licenses were issued by the Secretary of Commerce.

Of the first-grade operators 57 per cent. were 21 years of age or older, while 83 per cent. were 18 or older.

Of the second-grade operators 49 per cent. were 21 years of age or older, while 75 per cent. were 18 or older.

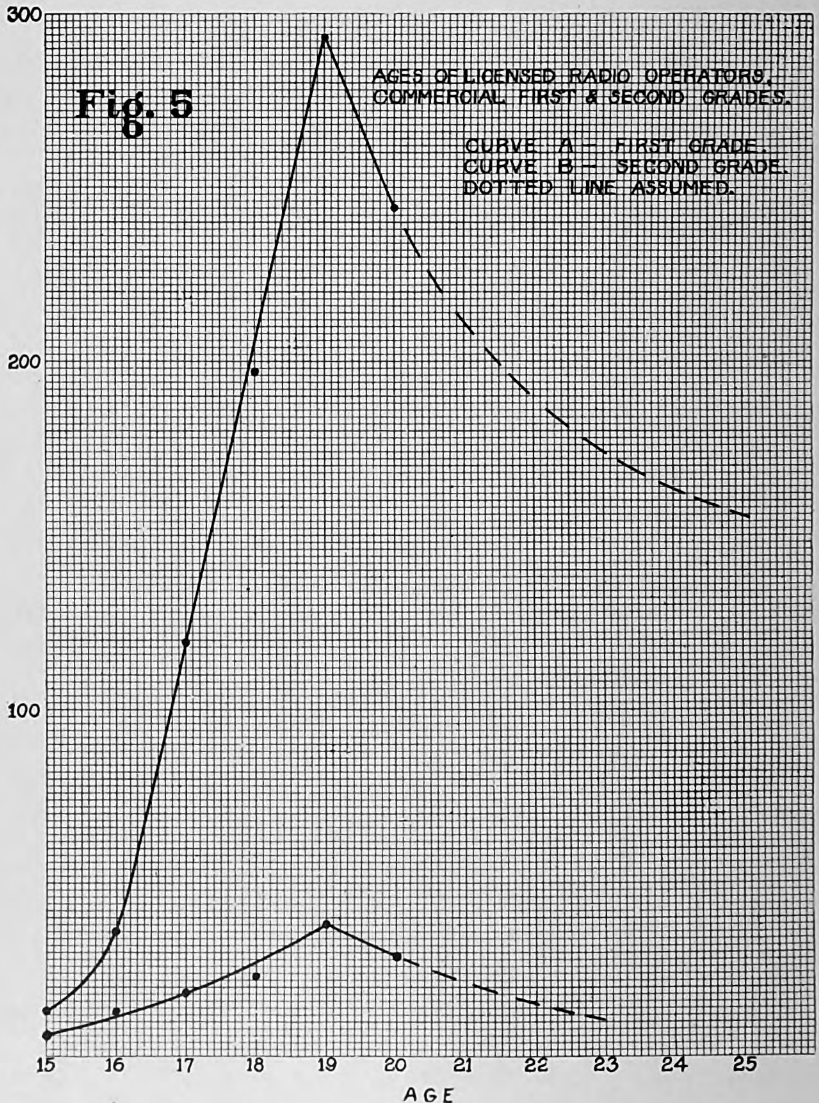
Of both grades 82 per cent. were 18 years of age or older.

*First-grade Operators.*

| Ages | Graphic | Number |
|---|---|---|
| 21 or older | | 1,197 |
| 20 | | 244 |
| 19 | | 293 |
| 18 | | 197 |
| 17 | | 119 |
| 16 | | 36 |
| 15 or under | | 13 |
| Total | | 2,099 |

*Second-grade Operators.*

| Ages | Graphic | Number |
|---|---|---|
| 21 or older | | 120 |
| 20 | | 29 |
| 19 | | 38 |
| 18 | | 23 |
| 17 | | 18 |
| 16 | | 13 |
| 15 or under | | 6 |
| Total | | 247 |
| Grand total both grades | | 2,346 |



300
200
100
Fig. 5
AGES OF LICENSED RADIO OPERATORS,
COMMERCIAL FIRST & SECOND GRADES.
CURVE A - FIRST GRADE.
CURVE B - SECOND GRADE.
DOTTED LINE ASSUMED.
15 16 17 18 19 20 21 22 23 24 25
AGE

It is interesting to note that most of the operators are 19 years of age. This is true of both the first and second grades. It is assumed that if the number 21 years of age and above were shown, the curve would drop down from 19 as indicated at 20.

The maximum at 19 may be accounted for if we assume that "wild oats" are usually ripe at about that age. I think that most young men who are suddenly imbued with a desire to leave home for a career at sea as radio operators are about 19 years of age. (Such was my own personal experience and while I do not advocate or approve of young men leaving school at this age, unless necessary, I believe the radio operating field offers such young men much better opportunities than many other lines of work that they might follow.) There may be other interesting psychological reasons accounting for this age maximum.

CONCLUSION.

We all know that there are good operators and some bad operators holding first-grade licenses who all passed the prescribed examination. There are also good physicians and some decidedly inefficient physicians practicing under licenses. I do not believe any examination can be devised which will bring out certain points as well as experience and practice.

As a recognition of experience, trustworthiness and efficient service the Department of Commerce now issues a special license known as "Commercial Extra First Grade" which is explained in Bureau of Navigation General Letter No. 69.

It is true that the successful operation of a radio station and to a large extent the range, depends a great deal upon the skill and experience of the operator. It is regretted that more experienced operators are not available. The dearth of experienced men as operators, especially for shipboard service may be due largely to the fact that the radio field is comparatively new and rapidly growing, and experienced men are often promoted to the higher positions mentioned previously. It is true that in the United States there are more than twice as many operators holding commercial first-grade licenses as there are operators employed as such. A cursory glance at the record seems to indicate that many radio employees holding higher positions maintain their operator's licenses for use in case of necessity, or as a matter of personal interest. Also a number of skilled and experienced amateurs not seeking employment have obtained commercial operators' licenses in connection with their small stations.

As I have mentioned before, the position of radio operator is the starting position in the radio field. Considering the rapidly increasing demand for radio operators I think it is really quite remarkable, on the whole, that the present standard of efficiency has been attained.

I believe operators are frequently held accountable for troubles and difficulties, the causes of which were entirely beyond their control, or the remedies for which requires a knowledge not warranted by the remuneration. It is a tedious and tiresome task to sit with telephones over one's ears by the hour, especially when there is no traffic, always on the alert for an emergency. Such service may mean long hours without sleep and even the loss of life.

Operators should be given opportunity to study, and special arrangements should be made to instruct them in the care, adjustment, and theory of the apparatus under actual service conditions.

They should be taught and required to comply strictly with all the rules and regulations, but this should be accomplished in a skilful manner without creating antagonism.

As the art advances improvements in the design of apparatus are being disclosed with a view to reducing and simplifying the adjustments which must necessarily be made by the operator. In connection with such improvements, I take this opportunity to protest against the term "fool-proof" which is too frequently used by radio engineers. I know from personal experience and it has come to my attention from other sources, that even *good* operators feel that the term as used is a personal affront. The terms, "rugged, automatic and self-adjusting" are suggested in lieu thereof.

I have received a number of personal inquiries from prospective radio operators as to the prospects and future possibilities for a young man entering the field as a ship operator. The field is new and rapidly growing. The public demand for radio communication renders the field permanent. My experience and observations convince me that the opportunities for advancement are far superior to those in many of the older trades or professions.

Below is given a table showing the rates of compensation for radio operators of the Navy, the American Marconi Company and the Tropical Radio Telegraph Company (United Fruit Co.), and the graded scales of promotion.

Subsistence is gratis for shipboard service and at some shore stations in the Naval, Marconi and United Fruit Services.

| U. S. Navy | American Marconi Company | United Fruit Company (Tropical Radio Telegraph Co.) |
|---|---|---|
| Per Month | | Per Month |
| *3rd class* $33.00 | 1st six months at $25.00 per month. | Juniors, $40.00 |
| *2nd class* $44.00 | 2nd six months at $30.00 per month. | Juniors, $50.00 |
| *1st class* $55.00 | Increase of $2.50 per month, each half year, to $40.00 per month. | Seniors, $60.00 |
| *Chief* $66.00 | Increase of $5.00 per month, each year, to $60.00 per month. | Seniors, $75.00 |
| | At shore stations increase of $5.00 per month, each year, to $90.00 per month. | Shore stations, $75.00 to $175.00 |
| | At trans-oceanic shore stations increase of $5.00 per month, each year, to $120.00 per month. | |

PROMOTIONS.

*Naval Service.*

On 1st re-enlistment the pay of each man is increased $6.99 per month.

On 2nd and subsequent re-enlistments the pay of each man is increased $4.79 per month.

If a man re-enlists for four years within four months after an honorable discharge, he receives four months' pay at the rate he was paid upon discharge.

There are other allowances and privileges, such as medical and dental attention, hospital privileges, retirement privileges after thirty years, on three-fourths pay with light and fuel allowance; six months' pay to beneficiary on decease; $1.00 a day for subsistence on shore at certain stations. Increased pay for permanent appointment as Chief Petty Officer, Seaman Gunner. Good conduct medals, etc.

*Marconi Service.*

Promotions indicated in foregoing table.

Gratuities in the nature of bonuses on messages are added to ship operators pay.

Operators stationed at trans-oceanic stations will be furnished board and lodging at the company's hotel at $35.00 per month.

*United Fruit Service.*

The first promotion from $40.00 to $50.00 is made at the end of two or three months, depending upon ability and aptitude shown.

The promotions from $60.00 to $75.00 at the end of about six months' service as senior depends upon aptitude shown and ability to "copy" direct on the typewriter in either the American Morse or Continental codes.

The promotions to shore stations and salaries paid depend upon vacancies, location of station and other conditions.

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If I have shown the necessity for more hearty coöperation between the radio operators and their employers and their superior officers, so that the radio laws and regulations, and the unwritten laws of good judgment may be intelligently complied with in the interest of safety to life at sea, I shall be satisfied.

**SUMMARY: The most important characteristics of the good radio operator are proficiency in the use of the code, skill in the care and adjustment of the apparatus, and reliability in an emergency. The requirements of the commercial companies of the Navy in these directions are considered. The American Morse code is compared with the Continental critically, and is adjudged superior. The use of the "Omnigraph" for test sending is favorably discussed. The requirements for an operator's license of any grade are given, and the problem of appropriate and searching examinations therefor is handled. The age distribution of radio operators is given graphically and numerically. The salaries and conditions of promotion of operators in the United States Navy, the American Marconi Company, and the United Fruit Company are compared.**

## DISCUSSION.

**E. T. Chamberlain:** Mr. Greaves' paper impresses me as an admirable statement from the administrative point of view, and is correct so far as I am familiar with the radio operator problem. Of course, I am not in a position to discuss the relative merits of the two telegraphic codes, but so far as the examination of operators for federal licenses is concerned, Mr. Greaves has expressed my own opinion. The examination system will be improved from time to time as experience and suggestions from those interested may prompt.

Questions of ages and wages will no doubt be automatically adjusted by the law of supply and demand, and in accord with the tendencies of the times.

**R. B. Woolverton:** I have found Mr. Greaves' paper very interesting, and many of his statements are corroborated by my own experience. I enthusiastically agree with him in his opinion that the American Morse code is far superior to the Continental code, especially with respect to speed; and as for accuracy thru static disturbances, my experience at the San Juan, P. R. station, which received almost entirely on long wave lengths, did not indicate that the Continental code was superior to the American Morse. It has always been my experience that even an expert operator receives good Morse by words, and Continental by letters; and besides there is an easy rhythmic swing to Morse which offsets any possible advantage which Continental might have.

Mr. Greaves' data regarding the number of operators at different ages is very interesting. There is one point in this connection, however, which I may point out. In the examination of 700 commercial operators I have been surprised to note that it is not the older, experienced group of operators which obtains the highest percentages. The keen, 19-year-old group of high school boys nearly always shows the higher percentages. Their knowledge of radio subjects, altho obtained largely from text books, is minute and very thoro. Their lack of experience causes lack of self-confidence, and the result is that they prepare themselves much more thoroly than the old experienced operators.

I heartily agree with all Mr. Greaves' statements regarding the Omnigraph. After long experience with the instrument I have found that in every case where the operator can really receive 20 words per minute with reasonable ease, he is always *pleased* with the Omnigraph's characteristic sending.

**David Sarnoff:** I heartily agree with Mr. Greaves in his opinion that the radio operator is a very important factor in the art of radio communication, and as such should receive careful consideration and study. The importance of the human element in the art of radio communication cannot be overestimated.

It seems to be an open question, as to which of the following combinations is preferable: An older and within reasonable limits, less efficient type of equipment in the hands of a skilled radio operator, or, a modern and more efficient set in the hands of a poor operator.

My own observations and experience in connection with the above problem leads me to answer the question in favor of the skilled operator. However, I fully appreciate the necessity and desirability of having the ideal condition, viz.: The good operator and the good set.

I note he says that "so far as safety at sea depends upon the radio operator, speed is not particularly important, altho it may be desirable under certain circumstances," and I do not think I can quite agree to the above. Speed in radio when speed can be utilized is perhaps more desirable and more important than in any other means of communication, for the reason that nearly all commercial ship and shore stations operate on 600 meters, and therefore make it necessary, particularly in crowded waters, to wait for the next fellow to "get thru." As a radio operator of a number of years of experience, I can now recall those painful moments of waiting. This is true not only in cases of ordinary commercial work, but also in cases of distress, to wit: the recent case of the steamship "Empress of Ireland," which only had six or seven minutes available in which to communicate During this time, the radio operator gave the Father Point station full particulars of his distress and received from that station the information and assurance of the assistance that would come to him in time.

We all know the number of sad cases, even to-day, where it takes a radio operator considerably more than six or seven minutes to despatch a single message, even if static and other interference are absent. As a general rule, an operator who is capable of telegraphing with speed, will utilize this ability when it is possible to do so, and as it is admitted that under certain conditions, speed is not only desirable but imperative, it must follow that an operator should have speed; and this applies not only in the case of commercial operators but to all operators engaged in radio work. It must be considered, however that

speed alone does not constitute the "good" radio operator. It is speed, plus stability, that is most effective.

With regard to the use of the Omnigraph as a means for testing operators' skill, I believe that there should be no objection to this instrument. I have personally used the Omnigraph and found no cause for complaint. Absolutely perfect sending is sometimes objected to by operators for the reason that they are not accustomed to it. I know that when the Marconi Company discontinued the use of manual transmission at Cape Cod and substituted the automatic, several ship operators complained of the sending the first two or three nights, but thereafter expressed their preference for the automatic. However, there is a difference between the automatic used at Cape Cod and the Omnigraph utilized by the Department of Commerce which, as explained, affords means for adjusting the character of sending.

American Morse vs. Continental.

I have used both American and Continental Morse in radio work, and believe with equal efficiency. Experience compels me to disagree with Mr. Greaves' opinion concerning the advantages of American Morse. Continental has proved itself to be by far the safer code in cable work and particularly so in radiotelegraphy. In my opinion, American Morse in radio can only be used by expert senders if any degree of accuracy is expected. Amateur sending can be interpreted to make all sorts of combinations, even by an expert receiver. In Continental this is not probable; and even indifferent sending is not so liable to be erroneously interpreted by the receiving operator, this being due to the absolute regularity of the Continental signals. Such regularity is a tremendous advantage in receiving radio signals thru static. The possible confusion which arises over poorly sent American Morse is best understood by a double code operator.

At this time when the advantages of the Continental code over the American Morse are so universally acknowledged and recommended for adoption by the American land wire companies, it may be interesting to quote an expression of opinion on the subject by so eminent a telegraph man as Mr. George G. Ward, Vice-President and General Manager of the Commercial Cable and Postal Telegraph System:

"I have read many articles in the past for and against the substitution of the Continental, or what might more appropriately be called the Universal telegraph alphabet, for the American telegraph alphabet, and, in my opinion and opinions of many

with whom I have discussed this question, including the eminent authority on all questions pertaining to telegraphy, the late Lord Kelvin, the Continental alphabet is by far the safer, and is also the quicker method of transmitting code messages by sound.

"In fact Lord Kelvin in a discussion I had the honor of having with him on this question stated to me that he could prove mathematically that the Continental code is faster than the American code, and altho I regret that I never pressed Lord Kelvin to make this demonstration, I fully believe that his statement was correct."

**V. Ford Greaves:** In cases of distress speed in operating is desirable if all the operators concerned are efficient, but in most cases it is not essential. It must be remembered that during the transmission of messages relating to distress the law requires a cessation of commercial traffic, thereby eliminating interference.

There appears to be some difference of opinion concerning the relative merits of the two codes, and as I said, we must bow to the overwhelming majority internationally in favor of the Continental.

I have had two years' experience as a two-code operator and my conclusions are all in favor of the American Morse.

It is my understanding that the Tropical Radio Telegraph Company have made exhaustive comparative tests employing expert operators in both codes working thru most trying conditions of static and interference and have found the American Morse several per cent. more efficient, based on net profits.

We regret that Lord Kelvin did not give us his calculations on the subject.

**John L. Hogan, Jr.:** It is indeed a pleasure to encounter a paper written in the spirit shown by this of Mr. Greaves'. While my opinion differs from his on a few of the subordinate matters expressed, my endorsement of his desire for a closer coöperation between executive, designing and operating forces than has been the rule in the past cannot be made too emphatic. The usual designer of radio apparatus seems to proceed upon the assumption of a hazy personal set of ideal operating conditions, and to lay out and build instruments which he believes will operate well when these ideal conditions are met. In the past this error has been made by every firm constructing radio apparatus of which I have knowledge, but it is gratifying to find that recently (at least in certain quarters) the matter of meeting actual present-day operating conditions has been closely studied and made use of.

The rivalry between exponents of the "American" and Continental Morse codes is always interesting. In the past five years I have made many trials of actual radio transmission of code and plain English dispatches, and in some cases have carried the tests along continuously for months. In every instance the Continental code has given better speed for equal accuracy or better accuracy at equal average speed, and I am therefore convinced by experience of its superiority. Accuracy must always be the element which determines the value of any telegraphic or telephonic communication.

Federal examination and licensing of operators is proving to be of great use to commercial radio corporations in spite of the fact that (as Mr. Greaves points out also) qualification for first-grade license does not in itself guarantee an operator to be entirely suitable for service. The examination is at least a big step in eliminating incompetent and useless men who have in the past harassed employers, as is attested by the fact that only one examination in nine results in a grant of first-grade rating. The operating companies owe the Department of Commerce a vote of thanks for this service.

I hope that the Institute will hear many more papers of such practical importance as this on "The Radio Operator Problem."

# THE OPERATING CHARACTERISTICS OF A THREE PHASE 500 CYCLE QUENCHED SPARK TRANSMITTER.[1]

By

Emil J. Simon and Lester L. Israel.

The use of a polyphase alternating current source to energize the oscillating circuits of a radio transmitter is not new in the art. Eisenstein in his patents[2] has clearly shown how this may be accomplished. For example, in his United States Patent Number 991,837, filed in August 1905, he shows (Figure 1) a three phase transmitting arrangement in which each phase energizes thru corresponding transformers three separate oscillating circuits having a common inductance directly connected in the aerial circuit. By this arrangement, Eisenstein hoped to accomplish several important results. First of all by greatly increasing the number of discharges per cycle in each phase, he desired to obtain a continuous or nearly continuous excitation of the antenna. (Figure 2.) This, he said, would enable him to use the arrangement for telephony. The greatly increased spark frequency meant a greatly increased total energy in the radiating circuit without an increase of the potential to which it would be charged. Eisenstein furthermore appreciated the many advantages to be obtained thru a satisfactory secrecy system. He claimed that he could produce this by using different wave lengths in the several discharge circuits, and that because of the high spark frequency (perhaps entirely beyond the limit of audition) the signals would be inaudible in a telephone.

Eisenstein unquestionably had the correct idea. At that time, however, shock excitation methods had not been disclosed to the art. The open spark-gaps which Eisenstein of necessity had to employ made the success of his much cherished plan impossible. The cause of the failure of his system is best described by quoting from Ernst Ruhmer's, "Drahtlose Telephonie:"[3]

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[1] Delivered before the Institute of Radio Engineers, New York, May 13, 1914.

[2] German Patent No. 176, 011; issued September 3, 1906.
German Patent No. 175,438; issued August 28, 1906.
U. S. Patent No. 991,837; issued May 9, 1911.

[3] "Drahtlose Telephonie," by Ernst Ruhmer, Berlin, 1907, page 88.

"Altho in the previously described sending system of Eisenstein no large intervals of time elapsed between the successive combinations of partial discharges and a continuous excitation of the transmitter takes place, a lack of constancy of time interval exists between the successive discharges; which, as we have seen, follow one another with increasing rapidity as the supply voltage is raised.

"Clearly this objectionable feature can be avoided only thru the use of high tension direct current applied to the spark gap."

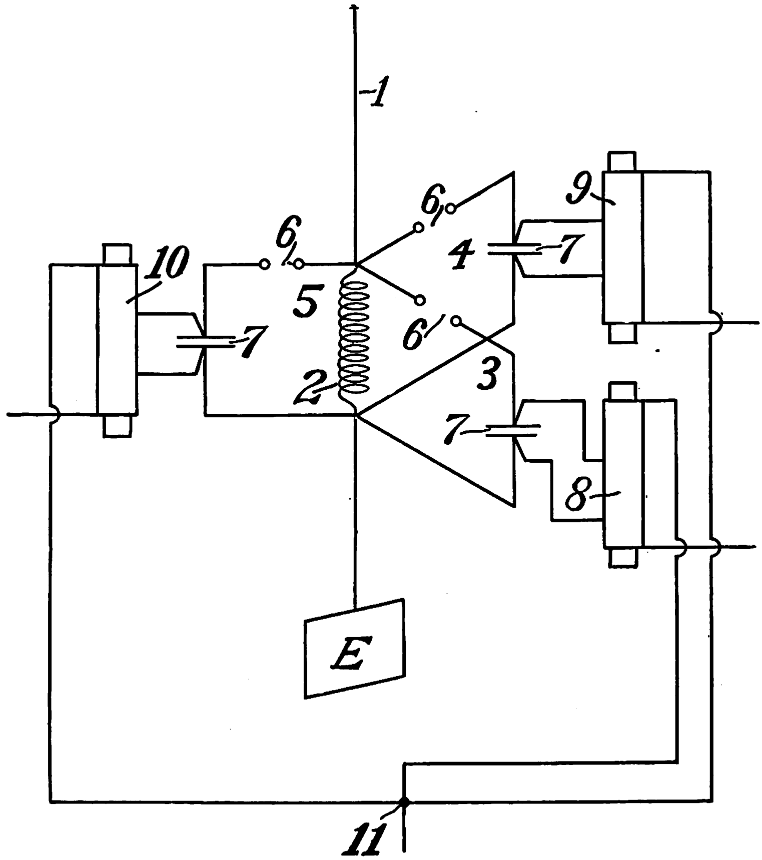


FIGURE 1

It was in the beginning of 1910 that the idea was first conceived of employing quenching spark-gaps in place of the open gaps of Eisenstein. In view of the state of the art at that time, such a substitution must have been obvious and surely required no great mental conception. However, it was felt, that this difference in degree, would be sufficient to distinguish success

from failure. The prevention of interaction between the antenna circuit and the closed oscillating circuits would enable a more rapid and at the same time uniform succession of spark discharges to be obtained. Again it was not long before those familiar with practical quenched spark operation recognized the limitations of power which such gap construction imposes. Here then appeared a method by which the power of a quenched spark transmitting set could be multiplied by as many times as the number of phases used.

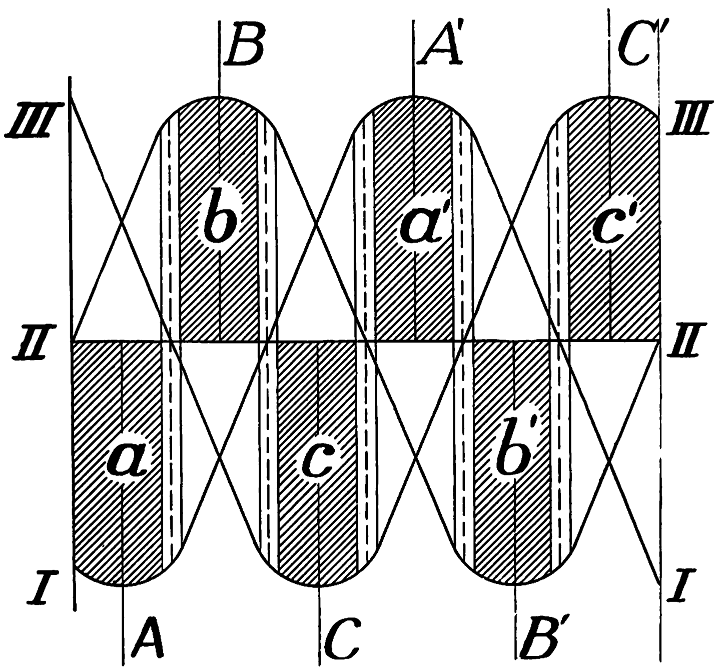



FIGURE 2

Seibt early recognized the great possibilities of a polyphase quenched spark transmitter. In his United States Patent application filed December 27, 1909 for: "Improvements in Apparatus for Producing Powerful Electrical Oscillations," claim 27 reads:

"In an apparatus for producing slowly damped electrical oscillations, the combination with coupled electrically oscillating circuits, of a three phase alternating current source for supplying energy to one of said circuits, said excited circuit having means for quickly snapping off the spark discharge in and opening said circuit consisting of spark gaps corresponding in number and

relative connections to the three phases of alternating source, the coupling of said inter-related oscillating circuits being sufficiently strong and adjusted to cause such opening of the said oscillating circuit substantially as described."

His method for accomplishing this result is shown in Figure 20 of his patent application (Figure 3). A recent exhaustive test has demonstrated beyond the question of a doubt that this arrangement of Seibt's is inoperative, because no appreciable

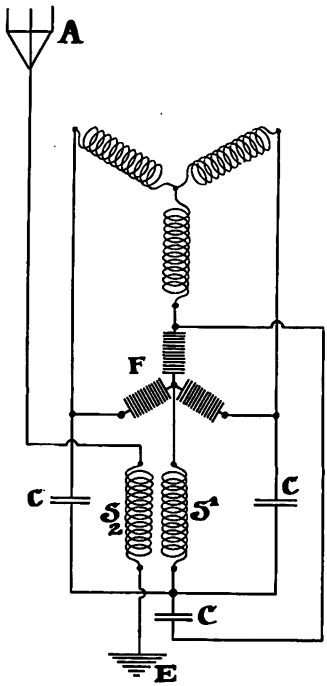


FIGURE 3

amount of current will flow thru the primary coil, S′, of the inductively coupled oscillation transformer.

It was not until the year 1913 that an opportunity presented itself of thoroly demonstrating the practicability of employing a polyphase alternating current. Stirred on by a patent situation which apparently gave to one radio company the sole right to use a high spark frequency in the transmitter, in conjunction with practical methods of reception used to-day, a three phase, 500 cycle generator of 7.5 kilowatt capacity was constructed. Preliminary tests made in the laboratory with the use of a dummy aerial showed sufficient promise to warrant the making

of further tests on a more extensive scale and in connection with a radiating antenna.

Thru the courtesy of the Navy Department, a series of tests were conducted last November, using the New York Navy Yard antenna. The apparatus consisted of three 2 kilowatt panel radio transmitters each individually energized by the separate phases of the 7.5 kilowatt 500 cycle three phase generator. The primaries of the low frequency or power transformers were connected in delta for convenience. The secondary of each oscillation transformer was connected in series with the antenna and ground. In order that the type of apparatus used may be clearly kept in mind, photographs (Figures 4 and 5) setting forth the essential features and diagrams of connections (Figure 6) are shown herewith.

As in almost every test of this kind there was some speculation as to the results that would be obtained. A casual inspection suggests at once that the effect of allowing these three practically independent quenched primaries to act on a single secondary oscillating circuit, will be to produce a 3,000 sparks per second tone in the telephone. As shown in Figure 7 the primaries would be expected to discharge 1–3000th second apart, and as the energy in all the primaries is immediately transferred to the common antenna circuit, there should be produced three sets of 1,000 spark wave trains evenly inter-spaced. It was expected that the maximum voltage produced by the three phases in the antenna circuit would be the same as that produced by one phase acting alone; and that the power input would be tripled, thus increasing by the $\sqrt{3}$* current produced by a single phase in the antenna circuit; and similarly for two phases that the tone would be 2,000 per second and the current increased by the $\sqrt{2}$.*

The real difficulty feared was that some change in the constants of the low frequency circuits would result which would alter their resonance condition. For example, if the phases were delta connected as shown in Figure 6, the transformers $T_2$ and $T_3$ would be connected in series across the transformer $T_1$, apparently changing the constants of this phase.

But as is usual in experiments of this kind, the preliminary speculations as to results and difficulties to be met were quite in error.

The first test made was to determine the effect of having the three phases act simultaneously on the antenna circuit. Each

* Power input varies directly as the square of the current.

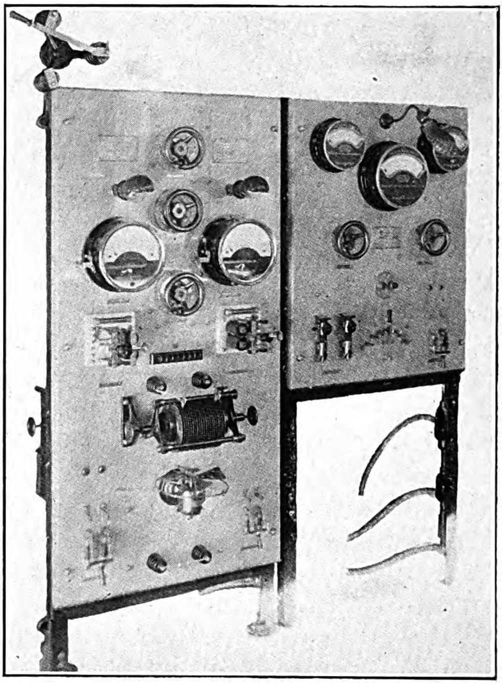


FIGURE 4

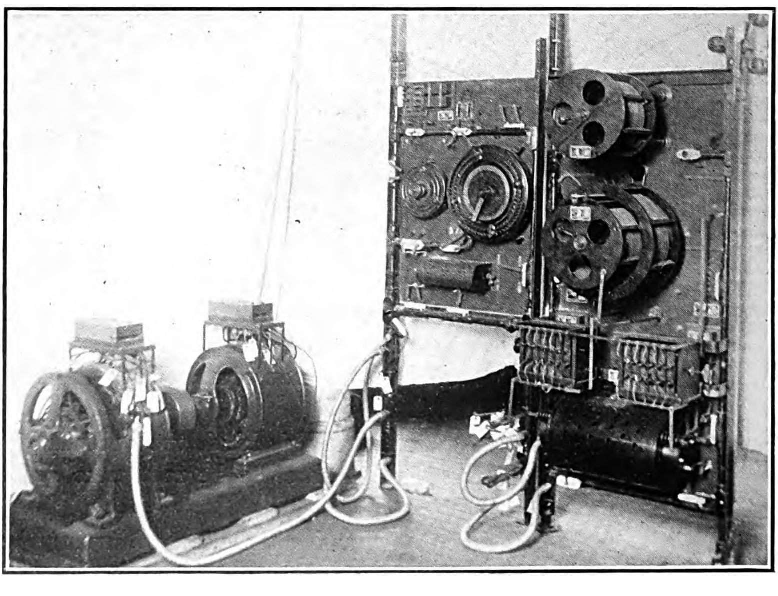


FIGURE 5

phase was separately adjusted to obtain a clear tone and maximum radiation at the common wave length to which the antenna circuit was tuned. Caution was exercised to have the quenched spark gaps of the phases A, B and C properly adjusted to a common generator voltage, because of the difficulty in attempting to vary this voltage separately for each phase. Thus approxi-

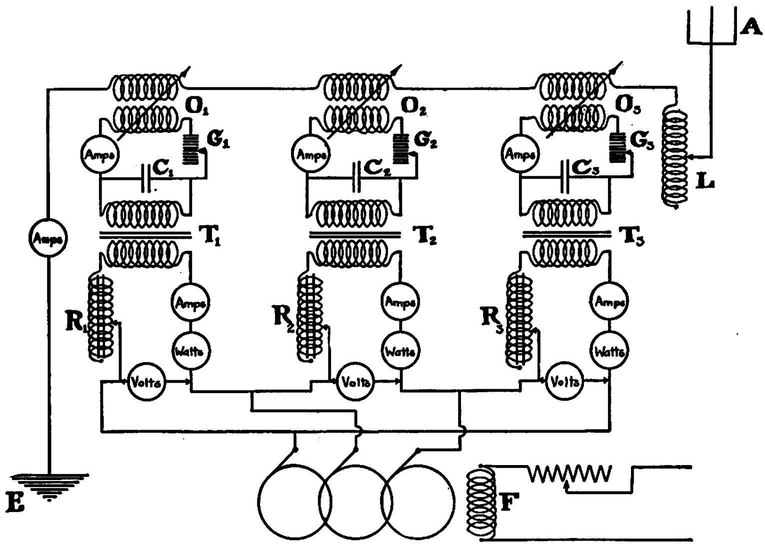



FIGURE 6

mately equal power was supplied by each phase. The readings for the three separate phases operating singly were:

| Phase | Gen. Output | Gen. Current | Closed Circuit Current | Antenna Circuit Current | Gen. to Antenna Efficiency | Mean Efficiency |
|---|---|---|---|---|---|---|
| A | 1.95 | 32 | 8 | 13 | 53.5% | |
| B | 2.12 | 25 | 8.5 | 15 | 66. % | 61.9% |
| C | 2.25 | 37 | 8 | 15 | 66.2% | |

When the three phases thus tuned were thrown on together and the generator voltage raised to compensate for drop due to increased load, the general change produced was to increase the generator and closed circuit currents. As shown in the following observations, the radiation did not increase in the ratio of $\sqrt{3}$, and the generator to antenna efficiency dropped from 61.9 per cent. to 36.2 per cent. The sound produced in a wave meter telephone had no tone characteristic, but was arc-like in nature.

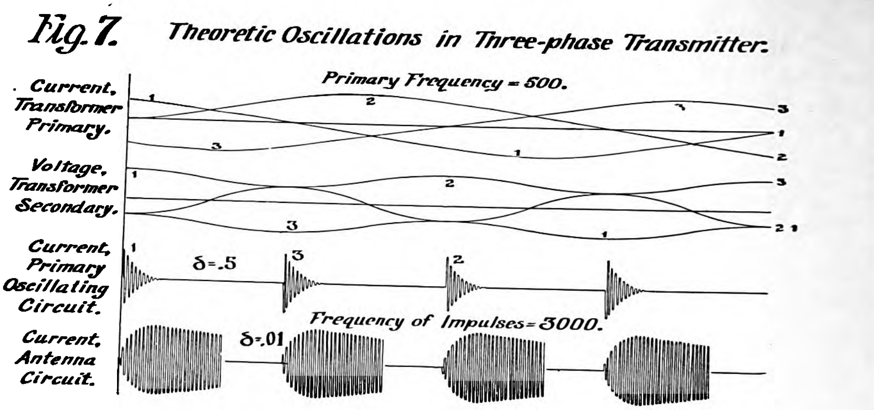



FIGURE 7

| Phase | Gen. Output | Gen. Current | Closed Circuit Current | Antenna Circuit Current | Gen. to Antenna Efficiency |
|---|---|---|---|---|---|
| A | 2.2 | 32 | 10.5 | .... | ...... |
| B | 2 | 28 | 9.75 | .... | ...... |
| C | 2 | 34 | 10. | .... | ...... |
| ABC | 6.2 | .. | .... | 19 | 36.2% |

These observations taken from a test conducted with Washington on November 13, 1913, show that with two phases alone the inter-acting effects were less noticeable than with the three phases and the 1,000 spark tone was not completely lost.

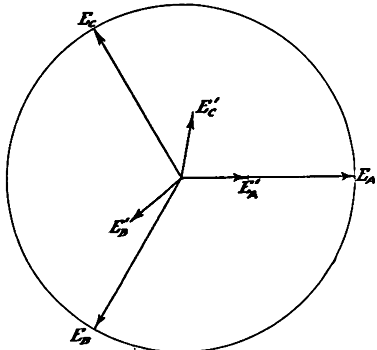
| Phase | Gen. Output | Gen. Current | Closed Circuit Current | Antenna Circuit Current | Gen. to Antenna Efficiency |
|---|---|---|---|---|---|
| A | 2.05 | 30 | 9.25 | .... | ...... |
| B | 2.05 | 29 | 9.25 | .... | ...... |
| A&B | 4.1 | .. | .... | 17.5 | 46.4% |

The procedure at first was to vary the low frequency circuit conditions by changing the primary reactance, the number of gaps, and the generator voltage and speed; first in the two, then in the three phases. It was found that any variation, except in generator voltage and speed, from the conditions of perfect single phase adjustment, merely made operation worse. The conclusion to be drawn was that the constants of the power circuits remain practically the same when operating with one, two or three phases. Thus the first and chief source of difficulty expected was found to be no difficulty at all!

The next step necessary was to vary the adjustments of the high frequency circuits. The wave lengths of the primary cir-

cuits were varied one set at a time; then two and three together. The coupling was similarly varied. As in the case of the low frequency circuits it was found that no change could be made that would increase the antenna current or over-all efficiency from the perfect adjustment for a single phase. Any change always resulted in a decrease of these values.

It was at about this stage, that owing to the tester's inability to discriminate between a 500 and 1,000 spark tone, a set of observations was unintentionally made with the sets adjusted to the lower spark frequency. This series of observations gave a noticeably higher efficiency with the three phases operating together than any previous series of observations. The experienced ear of Mr. Frank Hinners, who was called in to check up




$\left.\begin{matrix}E_A\\E_B\\E_C\end{matrix}\right\}$ = *Generated EMF's in phases A,B,&C.*

$\left.\begin{matrix}E'_A\\E'_B\\E'_C\end{matrix}\right\}$ = *Terminal Voltages in phases A,B,&C.*

FIGURE 8

the work, quickly noted the difference in pitch due to the diminished spark frequency. It was this fortunate mistake that at once suggested that the time interval between primary circuit discharges might affect the efficiency in some way or other. With this in mind, it was recalled that two phases were generally found to be more efficient than three. Here also the time interval between successive discharges is greater. A theoretical consideration of the phase displacements when only two phases were used led to the construction of the circle diagram shown in Figure 8. Altho this was only a rough approximation derived on the assumption of steady cyclic conditions, it showed that the operating phases tended to approach maximum or 180 degrees separation. The higher efficiencies obtained in these two cases

led us to suspect that the time interval between successive discharges was worthy of further investigation.

The first transmission test was conducted on the afternoon of November 13, last. The letters A, B, C, and ten second dashes were used, the letters to identify the phases in operation. Audibility observations were made simultaneously at the Bureau of Standards and at Arlington Radio Station, crystal detectors and telephones being used. The Fessenden Heterodyne receiver was made use of at Arlington in the reception of the three phases together. The observations recorded were as follows:

| Phases | Antenna Current Transmitter | Strength of Signals, Bureau of Standards | Strength of Signals, Arlington | |
|---|---|---|---|---|
| A | 13 | 32 X | . . . . . . | |
| B | 15 | 36 X | . . . . . . | |
| C | 15 | 42 X | 300 ohm | |
| AB | 17.5 | 55 X | 200 ohm | |
| AC | 17.5 | 65 X | 160 ohm | |
| BC | 17.25 | 60 X | 160 ohm | With Hetero-dyne |
| ABC | 19 | . . .* | 40 ohm | |

* Reading and spark tone poor.

The tone observed in a wave meter telephone at the sending station corresponded with that received at the Bureau of Standards and at Arlington. Resonance curves (Figure 9) taken during this test by Messrs. Geo. H. Clark and Guy Hill of the Navy Department showed a noticeable decrease in wave length and a substantial increase in the damping of the antenna circuit only when the three phases were used together. The maximum potentials developed in the antenna increased in the ratio of $\sqrt{2}$ and $\sqrt{3}$, but the current increased in less ratio. This was interpreted to mean that all three phases discharged together at intervals, and that reaction between antenna and closed circuits occurred. The energy of the three phases must have been completely and simultaneously transferred to the open circuit at some instants and then partly transferred back to the primaries. This could have occurred only if the wave trains in the antenna circuit, caused by the discharge of one phase, persisted until the discharge of the following phase.

With this theory in mind, we set about finally to verify or disprove our supposition. Assuming 1–3000th second between discharges, the following simple calculation showed that the amplitude of wave trains in the antenna at the time of discharge of the next phase was not negligible.

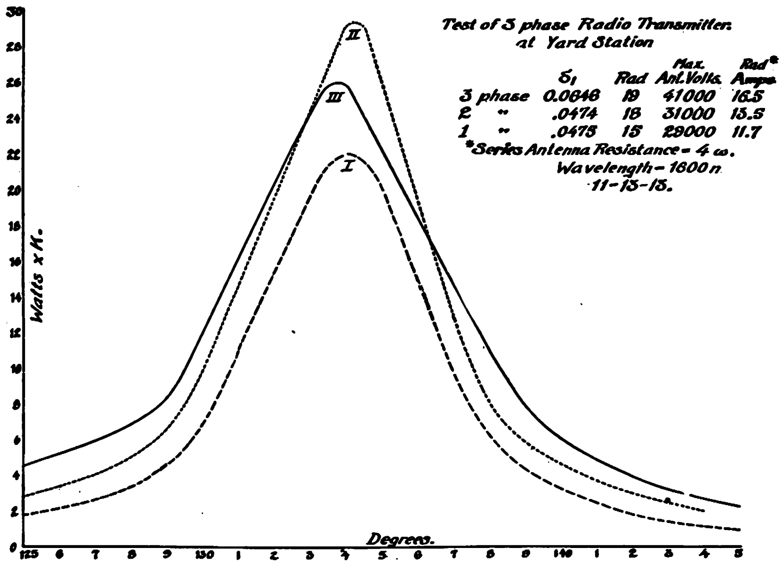



FIGURE 9

Taking the antenna constants as found in the first transmission tests; viz.:

$$
\begin{aligned}
&\text{Wave Length} &&= \lambda = 1{,}600 \text{ meters} \\
&\text{Period} &&= T = 1\text{–}187{,}000 \text{ second} \\
&\text{Decrement} &&= \delta = 0.0475
\end{aligned}
$$

We have:

$$\text{Waves per 1–6th cycle} = 1\text{–}3000 \div 1\text{–}187{,}000 = 62$$

$$\begin{array}{l}\text{Current amplitude at} \\ \text{discharge of next phase}\end{array} = I_{(max)}\ \varepsilon^{-62\delta} = \frac{I_{(max)}}{19.3}$$

i. e., the amplitude of oscillations in the antenna at the time of discharge of the next phase was at least 1–20th the maximum amplitude.

Now, the effective value of the maximum current is given by the equation:

$$I_{(eff)} = \frac{\omega\, C\, E_{(max)}}{\sqrt{2}} = 48 \text{ amperes}$$

where:

$$
\begin{aligned}
\omega &= 2\,\pi \cdot 187{,}000 = 1{,}170{,}000 \\
C &= 0.002 \cdot 10^{-6} \text{ mfd.} \\
E_{(max)} &= 29{,}000 \text{ volts}
\end{aligned}
$$

Thus the effective value of current in the antenna at the time of the discharge of the next phase was at least 2.4 amperes, indicating a substantial overlapping of consecutive wave trains.

A consideration of Figure 10 will give a clear idea of the reactions resulting from such overlapping. It will be seen first that it tends to build up the antenna potential amplitudes, so that at the time of the next discharge, this potential is proportionately increased. Furthermore, as the residual current in the antenna circuit impresses an E. M. F. across the condenser in the primary oscillating circuits, which compounding with the low frequency transformer E. M. F., causes the gap to break down earlier in the cycle, the time of the next discharge will be advanced. Finally, due to the conductive state of the gap, the residual energy in the antenna circuit will be partially transferred back to the primary circuit next discharging. This in turn accounts for the increased damping, the reduced wave length and lowered efficiency previously noted.

We reasoned further that if the overlapping of wave trains in the antenna was the cause of the phenomena observed, then a sufficient increase in the natural decrement of the antenna to diminish such overlapping, should increase the efficiency so as to equal that obtained by one phase alone. If the antenna damping could be further increased so as to make the wave trains entirely independent, a 3,000 spark tone should be distinctly audible.

Series resistance was accordingly inserted in the antenna circuit. This resistance was gradually increased, the high frequency circuits being carefully retuned. The curve in Figure 11 shows the effect produced. It will be seen that the generator to antenna efficiency reached a maximum when the total antenna resistance was increased to 13 ohms. It was noticed at this point that the hissing sound of the spark previously quite rough, now became smooth. Calculations showed that here the wave trains overlapped at 1–300th to 1–500th maximum current amplitude. As was to be expected, the 3,000 spark tone now became apparent.

With the antenna constants arranged to eliminate the harmful reaction between phases, so apparent in the first transmission test, a second test with Washington was conducted on November 17. The resonance curves (Figure 12) showed that the antenna decrement remained constant while using one, two or three phases. The antenna currents also increased in proper ratio. The maximum potential developed with the three phases,

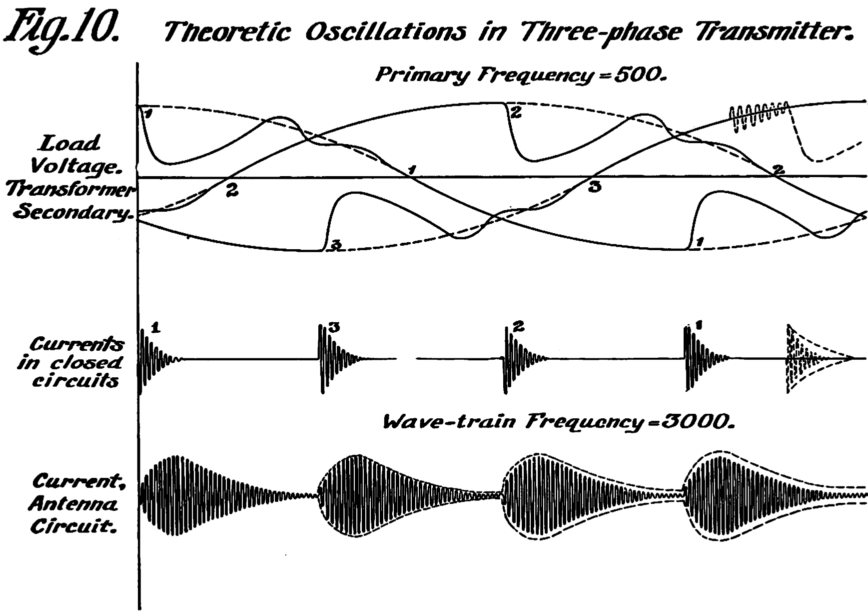



FIGURE 10

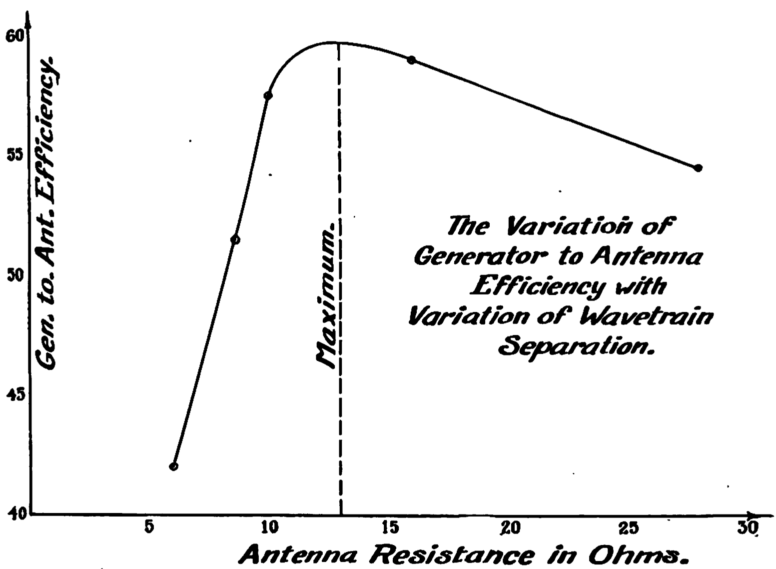



FIGURE 11

increased in the ratio of the $\sqrt{3}$ (over that of a single phase) showing that at some instant the three were still discharging together. The maximum potential developed in the antenna for two phases was 23,400 volts as compared to 21,000 volts for a

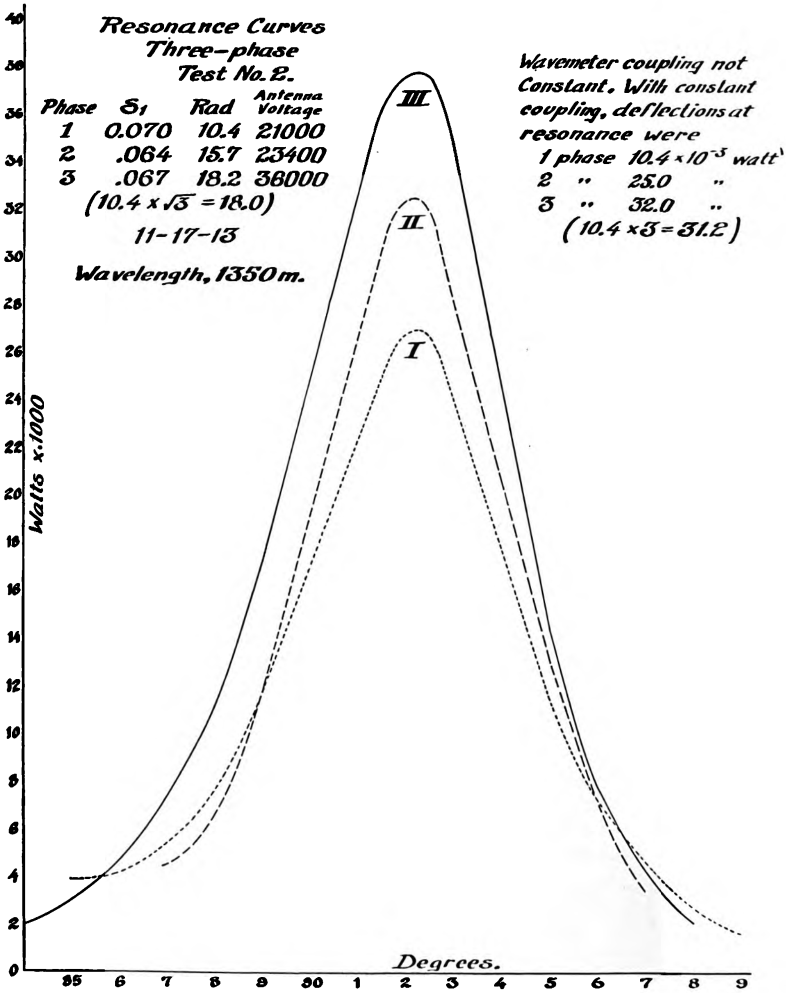



FIGURE 12

single one. It was evident that the inter-acting effects for two were less serious than for three.

One point still remained to be cleared up:—"What is the character of the discharges when the wave trains overlapped at 1–300th of the current amplitude or more?" As the observations

recorded at the Bureau of Standards in the last test indicated substantial increase in received energy, but a noticeable decrease in audibility, the wave train formation was evidently not of a very audible character.

A satisfactory explanation for this almost total loss of tone and a correct conception of the spark discharge frequency and resulting wave train formation, was not gained until quite recently. By courtesy of the officials of the New York Navy Yard, we were given the opportunity to use three ½ kilowatt panel sets in three phase connection employing a "dummy" antenna composed of compressed air condensers. Here we were able to observe the spark discharge frequency with the aid of a rapidly rotating neon tube connected to a high potential point in the antenna circuit. We experienced no difficulty in obtaining the pure 3,000 spark frequency as confirmed by telephone and stroboscope. By decreasing the damping of the dummy circuit to a minimum the wave trains were made slightly to overlap and total loss of this 3,000 spark tone followed. The number of discharges was evidently 3,000 per second but they appeared irregularly spaced, and this lack of periodicity accounts for the loss of tone. With two phases, the tone was similar to that of a 1,000 sparks per second, because the ear probably grouped into one the discharges of the two near phases.

These tests have demonstrated that the three phase operation at 500 cycles destroys the clear high pitched tone which is considered so essential for reliable telegraphic communication, in sufficient measure to compel the use of tikker or other similar methods of reception, wherein the received energy is broken up into periodic groups having a frequency well within the range of telephonic sensibility. The increased use of undamped wave transmission by important high power stations, will soon compel the majority of ship and shore stations to include in their equipment this effective and at the same time inexpensive type of receiver. Then the use of a polyphase high spark frequency telegraph transmitter may seem justifiable. However, it must be kept clearly in mind that the maximum wave length efficiently obtainable will be determined by the antenna damping; i. e., the greater the damping the greater the wave length which may be efficiently employed. Thus in long distance telegraphy, where high power is essential and where the antenna constants would be predetermined, the multiphase system may have many desirable characteristics. Three times as much power can be obtained using three phase current as compared with single

phase, the radiation is more continuous and the efficiency noticeably greater.

On the other hand, the use of a low spark frequency polyphase transmitter may find immediate application. There are many localities in this and other lands, where polyphase alternating current at lighting or power frequencies exists. Here a multiphase quenched spark transmitter of moderate power could emit a clear tone two or three times higher in pitch than would be possible with a single phase set. Except at extraordinarily long wave lengths, the overlapping of wave trains would be impossible. The saving affected by the elimination of the motor generator is an item worthy also of consideration.

The system described appears practical for telephony. By arranging the antenna constants so that the wave trains overlap by the proper amount the oscillations produced, even by a 500 cycle three phased transmitter, can be made completely to lose their tone characteristics. The high frequency radiation thus obtained is very constant, and causes only a slight steady hissing sound in the telephones. It is believed that the voice variations superimposed on this current would be effectively received especially if the generator frequency were further increased. A three phase 2,000 or 3,000 cycle generator can be readily constructed and should be entirely suitable for this use.

One point that has immediate practical importance has been clearly brought out by these tests. That is the effect of the overlapping of the wave trains. In the past it has been customary to think of wave trains as very widely separated. This was especially true in the days of high antenna damping, short wave length and low spark frequency. In modern 1,000 spark quenched gap sets, with wave length range up to 3,000 meters and with loading coils of reasonably low resistance this factor cannot be neglected. Several radio engineers conversant with 500 cycle quenched spark operation have recently noted that for a given generator output more gaps are required and that the efficiency of the sets rapidly diminishes as we approach the longer wave lengths.

It is believed that one of the most important causes of this variation is the overlapping of wave trains, and that this determines the upper limit of the wave length range which can effectively be used on any given antenna.

**SUMMARY:** The attempt to produce a nearly continuous radiation of energy and high tone frequencies by the use of polyphase transmitters is historically considered. The work of Eisenstein and Seibt is described. Experiments with two and three phase transmitters were made; and it was

found that the wave trains produced by successive discharges in adjacent phases overlapped in the antenna, thereby causing unmusical tones in the receiver and a diminution of transmitter efficiency. This decrease in efficiency is due to the increased reaction of the antenna on the closed oscillating circuits and the consequent disturbance of the regularly spaced spark discharges of the transmitters of each phase. By increasing the antenna damping, thereby lessening the overlapping of successive wave trains, the musical quality of the tone was improved and the transmitter efficiency markedly increased. Tests on dummy antennae and actual long distance tests were made. The production of practically sustained radiation, susceptible of reception by the use of the ticker or analogous devices, and produced by polyphase transmitters, is favorably considered. The limitation of quenched spark transmitter efficiency by the overlapping of rapidly successive wave trains is discussed.

## DISCUSSION.

**John Stone Stone:** It seems that practically the entire difficulty experienced by Mr. Simon in his experimental work arose from the irregularity of the spark discharges. Their regular sequence was disturbed by the over-lapping of the wave trains in the secondary circuit and by the reaction from the secondary on the primary circuit. To overcome these troubles, it was necessary to insert resistance in the aerial circuit, thereby increasing the damping of the wave trains to such an extent that the reaction of the secondary on the primary ceased until after the primary circuit current had been quenched. I desire to add, however, that the proper form of resistance to insert in an aerial for the purpose mentioned would be a carefully designed spark gap, of low resistance to high currents, but of high resistance to low currents.

The reason for the use of this form of resistance is that it would effectively eliminate the tail end of each wave train without seriously affecting the initial portions thereof. Since there is but little practically usable or sound producing energy at the end of the wave train, it is just as well if it is eliminated.

**Guy Hill:** In line with the suggestions of Mr. Simon regarding the overlapping of the wave trains in the antenna and the reaction of the aerial circuit on the closed circuit and of Mr. Stone's suggestion relative to the introduction of a spark gap as a resistance in the aerial circuit, I may mention that if by the introduction of such a gap, the reaction is appreciably diminished it might be well to adopt such measures, even in the case of single phase 500 cycle sets operating at very long wave lengths. This matter may well be worth going into.

**John L. Hogan, Jr.:** It has been suggested that if 60 cycle current were available, it would be possible by the use of a three phase transformer to obtain 360 sparks per second with the advantages of a high note at the receiving station. The National Electric Signaling Company has a very similar case to this in practice, at the New London station.

There we had 60 cycle, three phase current supplied. We thought of using there a three phase set, thereby getting a high frequency spark, but the simplicity and cheapness of installing a non-synchronous rotary gap giving musical spark of some 600 groups per second made the more complicated three phase set not worth considering.

Aside from the possibility of securing sustained waves, or radiation with very high train-frequency, for radio telephony or pure-note heterodyne operation, the only commercial use I can see for a three phase system is in very powerful stations for sending over long distances. It is possible that the triplication of parts necessary will be more than balanced in operating and first costs by the saving in the purchase of a 120 cycle, three phase or 60 cycle, three phase standard alternator instead of a 360 or 180 cycle special machine. This is speculative, however, and I am inclined to doubt the economic value of any multiphase system I have studied, especially when the trend toward sustained-wave and heterodyne operation is taken into account.

# A METHOD FOR DETERMING LOGARITHMIC DECREMENTS.*

By

Louis Cohen.

The only method available at present for the determination of the logarithmic decrement of damped oscillatory currents is the Bjerknes method, which depends on the following principle:—

A resonant circuit, comprising an inductance, variable condenser and a thermo indicating instrument, is loosely coupled to the exciting circuit the logarithmic decrement of which we seek to determine. The reasonant circuit is first adjusted so as to be exactly in resonance with the exciting circuit, and then slightly displaced from the resonance position by varying the capacity of the condenser, and the corresponding two current readings noted. Making use of certain formulae established by Bjerknes, we can evaluate the sum of the logarithmic decrements of the exciting and resonant circuits from the values of the current readings thus obtained. The formulae derived by Bjerknes for this problem are as follows:—

When the two circuits are in resonance, the square of the current in the resonant circuit is given by the expression:

$$I_r^2 = \frac{E^2}{16\, L_2^2\, \alpha_1 \alpha_2 (\alpha_1 + \alpha_2)}. \tag{1}$$

For the non-resonant condition, the square of the current in the resonant circuit is given by

$$I^2 = \frac{E^2}{16\, L_2^2} \cdot \frac{\alpha_1 + \alpha_2}{\alpha_1 \alpha_2} \cdot \frac{1}{4\pi^2 (n_1 - n_2)^2 + (\alpha_1 + \alpha_2)^2}, \tag{2}$$

where $\alpha_1$ and $\alpha_2$ are the damping factors of the exciting and resonant circuits respectively, and $n_1$ and $n_2$ are the free oscillation frequencies of the circuit when in resonant and non-resonant conditions respectively. From the two formulae given above, we can easily derive an expression for the sum of the damping factors of the two circuits, which is as follows:—

$$\alpha_1 + \alpha_2 = 2\pi (n_1 - n_2) \frac{I}{\sqrt{I_r^2 - I^2}} \tag{3}$$

* Delivered before The Institute of Radio Engineers, New York, March 4, 1914.

The sum of the logarithmic decrements per complete period of the two circuits is

$$\delta_1 + \delta_2 = 2\pi\left(1 - \frac{n_1}{n_2}\right)\frac{I}{\sqrt{I_r^2 - I^2}}, \tag{4}$$

The above expression is simplified if we adjust the capacity for the non-resonant condition so that the square of the current is reduced to one-half the resonance value, and also express $n_1$ and $n_2$ in terms of the capacities corresponding to these frequencies, and in this case formula (4) reduces to

$$\delta_1 + \delta_2 = \pi\frac{C_1 - C_2}{C_2}, \tag{5}$$

where $C_1$ and $C_2$ are the capacities corresponding to the resonant and non-resonant condition respectively.

The above formula is the one commonly used in the measurement of logarithmic decrements, and in the design of decremeters.

The limitations of the Bjerknes formula are well known. Certain approximations are introduced in the derivation of formula (2) which must be taken account of in every case, or the results may be in error as has been shown experimentally by Eccles and Makower.* It is very desirable, therefore, to develop another method for measuring logarithmic decrements which may be used as a check on the older method, and if found suitable may be introduced into general practice.

The method suggested here for the measurement of logarithmic decrements, is as follows:

As in the case of the Bjerknes method, we couple loosely to the exciting circuit a resonant circuit comprising an inductance and a variable condenser, and adjust it so as to be exactly in resonance with the exciting circuit. The value of the square of the current in the resonant circuit is given by

$$I_r^2 = \frac{E^2}{16\, L_2^2\, \alpha_1 \alpha_2 (\alpha_1 + \alpha_2)}, \tag{6}$$

when as in the previous formulae $\alpha_1$ and $\alpha_2$ are the damping factors in the exciting and resonant circuits. Now suppose an additional non-inductive resistance is introduced into the resonant circuit changing the resistance $R_2$ to $SR_2$, where S is

*"The Efficiency of Short Spark Methods of Generating Electrical Oscillations." W. H. Eccles and A. J. Makower. *The Electrician*, Vol. 65, page 1014, Sept. 30, 1910.

greater than unity. Evidently the damping factor $\alpha_2$ is also changed in the same ratio and the current is reduced. If we designate the value of the current for this case by I, we shall have

$$I^2 = \frac{E^2}{16\,L_2^2\,\alpha_1\,S\,\alpha_2\,(\alpha_1 + S\,\alpha_2)}. \tag{7}$$

From (6) and (7) we get by division,

$$\frac{I^2}{I_r^2} = \frac{\alpha_1 + \alpha_2}{S\,(\alpha_1 + S\,\alpha_2)}. \tag{8}$$

If we vary the amount of additional resistance introduced into the resonant circuit until the square of the current is reduced to one-half the original value, we shall have by (8)

$$\frac{\alpha_1 + \alpha_2}{S\,\alpha_1 + S^2\,\alpha_2} = \frac{1}{2}. \tag{9}$$

Hence

$$2\,\alpha_1 + 2\,\alpha_2 = S\,\alpha_1 + S^2\,\alpha_2,$$

and

$$\alpha_1\,(2 - S) = \alpha_2\,(S^2 - 2),$$

or

$$\alpha_1 = \frac{S^2 - 2}{2 - S}\,\alpha_2. \tag{10}$$

We have here the value of $\alpha_1$, the damping factor of the exciting circuit, expressed directly in terms of $\alpha_2$. If the resistance and inductance of the resonant circuit are accurately known, the value of $\alpha_2$ is also known, and we can then obtain the value of $\alpha_1$ from equation (10). Knowing the value of $\alpha_1$, the logarithmic decrement is

$$\delta_1 = \frac{\alpha_1}{n}. \tag{11}$$

In practical work it may prove difficult to obtain a sufficiently fine variation in resistance so as to reduce in every case the square of the current to one-half its resonance value, but this is not necessary. Suppose we introduce a fixed resistance in the circuit which will cause a reduction of the square of the current to some fraction of the resonance value which we may designate by m, we have by equation (8)

$$\frac{I^2}{I_r^2} = m = \frac{\alpha_1 + \alpha_2}{S\,(\alpha_1 + S\,\alpha_2)}. \tag{12}$$

From the above we can easily obtain the value of $a_1$ in terms of $a_2$ which is as follows:

$$a_1 = \frac{m S^2 - 1}{1 - m S} a_2. \tag{13}$$

Putting $m = \frac{1}{2}$, equation (13) reduces to (10).

The method outlined above would be very simple in operation and ought to give accurate results if the constants of the resonant circuit are carefully determined. This method would be especially suitable for measuring small logarithmic decrement, because $a_2$ can be made small, and we therefore express one small quantity in terms of another small quantity.

To embody the principle suggested here in the design of decremeters, it is necessary only to have a resonant circuit the resistance and inductance of which are accurately known for the range of frequencies for which the instrument is to be used. A set of curves could be prepared to go with each instrument giving the values of $R_2$ and $a_2$ as functions of the frequency. Knowing the value of $R_2$, the value of S can be readily obtained from the known increase in resistance required to reduce the square of the current to one-half the original value, and we thus know all the factors which enter into formula (10). The frequency of the oscillations can, of course, be obtained with the same instrument.

**SUMMARY:** The Bjerknes method of determining the logarithmic decrement of the secondary of two coupled circuits is critically discussed. The Author suggests a new method for determining this decrement. An additional known resistance is inserted in the secondary (or resonant) circuit instead of in the primary circuit as is the case in the Bjerknes method. An expression for the logarithmic decrement of the secondary circuit in terms of the logarithmic decrement of the primary, and known or measurable quantities, is given. The practical application of the method is described.

## DISCUSSION.

**John Stone Stone:** This is a most interesting contribution to an important subject.

From the nature of the tests described, it is evident that S can range only between $\sqrt{2}$ and 2 (or 1.414 and 2). The ratio S must, therefore, be determined with extreme precision, particularly when the ratio $\frac{a_1}{a_2}$ is small. The determination of these resistances with great accuracy on the other hand is not always very easy in the case of the high frequencies which occur in radio work. As an example of how great this precision may have to be in a given case, it is to be noted that an error of $\frac{1}{2}$ of 1 per cent. in the ratio S will make an error of more than 100 per cent. in the ratio $\frac{a_1}{a_2}$ if $\frac{a_1}{a_2} = 0.068$, or approximately $\frac{1}{15}$. On the other hand, when the ratio $\frac{a_1}{a_2}$ is 20, an error of ½ of 1 per cent. in the ratio S gives rise to an error of 16 per cent. in the ratio $\frac{a_1}{a_2}$. When however the damping co-efficients or constants of the driving and driven circuits are not very different from each other ($\frac{a_1}{a_2}$ nearly unity) the method is subject to no such radical objection and should prove useful in the connection pointed out by the Author.

The difficulty I have indicated is perhaps not insuperable, however, for if the ratio of $\frac{a_1}{a_2}$ be not favorable to precision of measurement, it may be possible to add known resistances to both circuits until the ratio is favorable and then to take these added resistances into account in the final result.

It would seem, however, that in this case it might be necessary to resort to more than a single measurement and under these circumstances the test would lose its chief advantage, viz.: its beautiful simplicity which so highly commends it in the cases to which it is directly applicable as described by the Author.

**Frederick A. Kolster:** This paper deals with a subject in which I have been very much interested for some time, particularly in connection with the Bjerknes method of obtaining logarithmic decrements.

That there are limitations to the use of the method of Bjerknes is, of course, well known, but I am of the opinion that in practice these limitations are not so serious as the results of some experiments have indicated.

Mr. Cohen gives a reference to a paper by Eccles and Makower, which gives the results of some experiments in which the resistance of a circuit is determined from the decrement. It is not at all clear that the large errors obtained in these results are due to the limitations of the Bjerknes method and it is very reasonable to believe that they are due to other causes. I have made many tests similar to those of Eccles and Makower to check the accuracy of decrements obtained by the Bjerknes method and have always obtained excellent results.

In connection with the method given by Dr. Cohen, I am not convinced that there are sufficient advantages in it to warrant its general use in preference to the Bjerknes method. So far as the measurement of small decrements is concerned, the limitations of the Bjerknes method are in such cases, greatly reduced, and by far the most important source of errors lies in the measurement of $\delta_2$.

To make use of the simplified formula (10), an accurately calibrated adjustable high frequency resistance is required in order that the half deflection condition can readily be obtained. This introduces an undesirable feature as it is difficult to determine with accuracy the true high frequency value of such a resistance.

To determine S in formula (10), $\Delta R$, the value of the inserted resistance, and $R_2$, the resistance of the instrument must be accurately known; and unless they are determined with great precision, any advantages which the method may possess, quickly disappear, as can be seen by the way the value of S enters into the formula (10). For example, an error in S of 0.5 per cent., for $S=1.60$, will produce an error in the value of $\delta_1$ of nearly 7 per cent.

It is interesting to note that formula (8) is identical with the well known formula,

$$\delta_2 = \Delta\,\delta \frac{I^2\left(1 + \dfrac{\Delta\,\delta}{\delta_1 + \delta_2}\right)}{I_r^2 - I^2\left(1 + \dfrac{\Delta\,\delta}{\delta_1 + \delta_2}\right)}$$

which is sometimes used in determining $\delta_2$ rather than $\delta_1$.

**Louis Cohen:** Messrs. Stone and Kolster are entirely correct in their contention that to get reliable results by the method described in my paper it will be necessary to determine the value of S with great precision. The difficulty, however, is not so serious as it may appear. The resistance of the resonant circuit can be made very small by using small inductance and large capacity and by having the coil wound with low resistance stranded wire. Now suppose we introduce an additional resistance of about 5 ohms or more, which shall form part of the circuit; the resistance of the coil will then be only a small part of the total resistance in the circuit, and any error in the value of the high frequency resistance of the coil will therefore be inappreciable when taken in connection with the total resistance of the circuit. The added resistance may be in the form of fine straight wires of a high resistance material, whose high frequency resistance can be determined very accurately. If the resistance of the coil is ½ ohm, and the additional resistance is 5 ohms, then an error of even 5 per cent. in the value of the resistance of the coil, will introduce an error of only 0.4 per cent. in the total resistance of the circuit.

Similarly, the resistance which is to be further added in circuit to reduce the current can also be in the form of straight wires of high resistance material. In fact it will only require to have a number of small high resistance wires properly mounted, and by means of a switch to introduce as many as may be necessary until a certain reduction in the current is obtained, and then make use of Formula (13) to calculate the value of $a_1$.

In the case of straight wires the high frequency resistance can be calculated to any degree of accuracy desired, but even if there should be a small error, it will enter in about the same ratio in both readings, and the value of S will not be affected.

Volume 3 lacks nos. 1-3

VOLUME 3 DECEMBER, 1915 NUMBER 4

# PROCEEDINGS
*of*
# The Institute of Radio Engineers
(INCORPORATED)

TABLE OF CONTENTS

TECHNICAL PAPERS AND DISCUSSIONS

INDEX TO VOLUME 3

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THE TABLE OF CONTENTS FOLLOWS ON PAGE 305

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# CONTENTS



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**Following the Index at the end of this number are the title page, page of general information, and table of contents page for the entire Volume 3 (1915) of the PROCEEDINGS. These last may be suitably placed at the beginning of the volume for binding.**

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It is with deep regret that the Institute of Radio Engineers announces the death of

## Mr. N. H. C. Taylor

He was the radio operator on board the steamship "Marowijne," which foundered with all on board during a hurricane on the Caribbean Sea on August 14, 1915. Mr. Taylor, who was an Associate Member of the Institute, was in the employ of the Tropical Radio Telegraph Company at the time of his death.

The heroic steadfastness required by the radio operator in stress and storm is shown by this catastrophe.

# THE TRAINING OF THE RADIO OPERATOR*

By

M. E. Packman

In contra-distinction to the advance that has been made by the scientific and commercial development of radio telegraphy, the operator problem stands much as it did in the earliest days. While radio equipment has undergone many improvements, traffic departments have accomplished much in the organization and collection of business, and the number of equipments has greatly increased, little has been done to increase the efficiency of the operating staff. In former days the only question asked of a man applying for a position as wireless operator was, "Are you an operator?" Since the advent of the Government License it has been changed to "Have you a license?" An affirmative answer was and is, in the majority of cases, all that is required to secure the applicant his position. In some cases, this was necessary; and it will undoubtedly continue to be so inasmuch as it is not always possible to obtain a competent man at the particular moment that an operator is needed. It seems, however, that if the question of the training and selection of operators for radio service were handled in a manner more in accord with that followed by railroads, the deplorable condition that exists in some land and ship stations would be greatly improved. As all persons acquainted with the commercial development of radio communication in this country well know, a very chaotic state of affairs existed prior to the time that the Department of Commerce placed certain restrictions on radio equipment, operators, and methods of operating. After the matter of wave length restrictions has been more nearly adjusted to meet present conditions, I think it will be possible to say that as a whole conditions have been much improved.

As far as the operators are concerned, the Government examinations have weeded out many undesirable men from the service and consequently have raised the standard a little higher, but it must be borne in mind that the Department of Com-

* Presented before The Institute of Radio Engineers, New York, October 6th, 1915.

merce looks at the efficiency of the operator from a different point of view than should the commercial company if it is seeking the most suitable men. The requirements of the department are only a part of what good commercial service demands, tho in many cases a first grade license is all that is required or asked for.

As one man of my acquaintance, who employs a great many operators every year has stated in referring to the operators on his ships, "Some of these men cannot send, some of them cannot receive, some of them cannot adjust a detector, and some of them cannot tune." Such men as he refers to, that do little else than ride back and forth on the ships, are common in the radio service everywhere; and the excuse is made that it is difficult to find men who are good telegraphers and at the same time are capable of handling a radio set to the greatest advantage. This condition is the natural result of attempting to get efficiency out of men who have had no telegraphic experience or who have had no training in the use of commercial radio apparatus. I have known men whose highest aim in life was to be so expert a telegrapher that they could sit down and work any telegraph circuit at which they might be placed. On the other hand, there are radio operators who are interested only in the handling of the instruments; and again there are men who have no particular interest in any phase of the business, other than its outside attractions. Obviously none of these classes of men completely fill the requirements of a "good" operator, but this list includes practically all the available men, with few exceptions, who have not been specially trained.

A question then arises: what are the qualifications of a "good" operator. In the first place, he should be capable of transmitting signals clearly, accurately, and rapidly in either American Morse or Continental Morse. He should understand that any communication not only has to be sent but also to be received; and realizing this, he will space his characters and words so that they will be easily understood by the receiving operator. He should know when to repeat and when it is unnecessary, when to send slowly and when he may send faster. In receiving, he should be able to read almost any kind of sending, and to make a neat copy with either pen or typewriter regardless of whether he has interference to contend with or not. If he is capable of getting the most out of his instruments he must thoroly understand the principles which underlie their design. This knowledge must be so perfect and of so practical a nature

that he will know instantly what is needed in case of emergency or disaster. He must have a comprehensive knowledge of telegraphic tariffs, traffic, methods of routing, the location of various radio and telegraphic stations, etc., so that he can quickly determine in what way a message can be handled with the greatest dispatch and least expense. This will not only be an aid to him in procuring business but it will be of benefit to the general public with whom he deals. He must be ready and willing to perform the functions of his office at all times; and in every case he must be a gentleman.

Some of the qualifications enumerated involve inborn personal characteristics that are apart from any training that a school can give. Experience has shown that one phase of the work will appeal more strongly to one man than another and that it is seldom the case that a man of his own initiative becomes proficient in all the things essential to his work. I think it can be said, however, that given a man with average intelligence, willingness, and six months training in a well organized school; a proficient radio operator can be developed.

The object of this paper is briefly to outline the course in "Radio Telegraphy" as given at Dodge's Institute of Telegraphy at Valparaiso in Indiana, and to show some of the methods that are used in an effort to meet the requirements of a comprehensive training for radio operators or other persons interested in the art of radio communication. More than one-third of the students entering the school are enrolled in the Radio Department, and of this number about two-thirds also take the work in the Morse Department, thus familiarizing themselves with both codes. Aside from the special work in each of these departments all students are required to take a half hour's work in penmanship, under a competent instructor, each day. To anyone familiar with telegraphic work, the importance of this is apparent. The school is also equipped with a large number of typewriters so that the student may become proficient in copying directly from the circuits by this means. The greater portion of the students completing the course in Radio Telegraphy enter the service of the Marconi Wireless Telegraph Company with which company we have a working arrangement. Others of these students enter other commercial or government service.

As might be expected in an institution of this kind the student body is made up of all classes. The students are of all ages, and they come from all parts of the United States; many of them come even from foreign countries. Some of those who

enroll in the Radio Department, especially, are college graduates; many are high school graduates, while some of them have very meagre education. Altho we have no regular entrance requirements, as far as education is concerned, it is frequently the case that we are compelled to refuse the applicant because of his lack of elementary education. The average student is between eighteen and twenty years of age and has had two years of high school training. This is, of course, a desirable qualification, and I have found that those students who have had amateur experience together with the high school work are the most apt in mastering the radio work. This is due, of course, to their great interest in the radio field. Another class of men that invariably develop into excellent radio operators is drawn from the commercial and railroad fields. There is also a great variance in the ulterior motives of the different students. The majority of them, of course, expect to prepare themselves for service as commercial radio operators. However, we have many special students with entirely different objects in view. Among these are men from the armies and navies of foreign countries as well as some from the United States government service. We have other students who are interested in the subject from a scientific standpoint only, some who expect to teach the subject in other schools and colleges, and so on.

In arranging a course that will meet these varied conditions, numerous points had to be considered. In the first place, it is impossible in most cases for the student to remain in school for a period exceeding six months. This means that all the work relating to the subject must be covered within this time at most. In the second place, owing to the lack of preparatory training in electrical science, it is necessary to begin with the very principles of electricity; and considering the extent of such electrical knowledge that an operator should have, and the complexity of some electrical ideas, it requires a very careful selection of the subject matter in order that the course be made as comprehensive as possible. Many of the theories which underlie the working of radio apparatus, involve the principles of alternating currents, a subject which is usually taken up in the third or fourth year in engineering courses; and altho simple to an electrical engineer is very complex and difficult of explanation to a student who has no foundation for such work. Nevertheless, these ideas have to be covered in order that the student is eventually able to reason out many of the problems and questions that may present themselves sooner or later. In our work the students are not

shown lists of questions, the answers to which can be memorized, and their examinations are the result of actual knowledge of radio apparatus, its uses, merits, and failings. This, it appears, is the only possible manner in which a "good" operator can be trained so far as theory and manipulation of apparatus are concerned.*

In general, the theory, adjustment and operation of radio equipment is given in a series of lectures associated with laboratory work, which occupies three hours each forenoon, five days per week. The beginning class is held between 11 and 12, an intermediate class between 9 and 10, and the advanced class between 8 and 9. The hour between 10 and 11 is devoted to code practice. Other code classes are held from 1.30 to 3 P. M., 4 to 5 P. M., and 7 to 8 P. M. The penmanship class is held between 3.30 and 4 P. M. During the summer months, the evening session is discontinued. In describing the various parts of the course, I shall take up the code work first.

At the time the Department of Radio Telegraphy was established, the American Morse code was used almost exclusively in the radio service in this country, the South Wellfleet station being the only one that used Continental Morse extensively, so far as I am informed. With this condition existing, it was a simple matter to train a Morse operator to receive the same code thru telephone receivers. In the Morse Department of the school, there was and is every facility for training a student in Morse receiving where there are a great variety of speeds. A new student is started on a circuit where an instructor makes the characters of a letter and the student pronounces the letter; and as he becomes familiar with the combinations forming all the letters, he is advanced to a circuit on which short words are sent, which he calls off as he recognizes them. In this way a student is advanced from one circuit to another until he is receiving at a speed of twenty-five to thirty words per minute. On the more advanced circuits in the commercial and railway department, the instruction consists of commercial and railway messages or train orders. Examinations are held from time to

*One method of preparing a man for a government license, which I have been informed is used, is to furnish the student with a list of questions, such as are used by the inspectors in examining applicants for operators' licenses, together with the correct answer to each question. With such a list of questions and answers, it is a simple matter for a telegrapher to pass the examination as given by the Department of Commerce, provided he does not write down answer six for question five. Such a man is of course worthless in actual radio service altho he has nevertheless passed the requirements of the Department of Commerce.

time and the students making the fewest mistakes in their copies, which are marked with care, are advanced to higher circuits.

After a student who had enrolled in the radio course had progressed to the point where he could receive eighteen to twenty words per minute from a sounder, he was transferred to the radio code work. All such students were supplied with practice sets including a single slide tuning coil, detector, fixed condenser, head telephone receiver, and sufficient aluminum wire to construct an indoor antenna, as well as a key and buzzer mounted on a base board. An operator at the radio station in the school sent press matter at a speed of about fifteen words per minute for a period of an hour and a half or so, and at a faster speed for an equal period. Students, supplied with the small receiving sets which they had installed in their rooms, were supposed to spend the afternoon in copying these signals. This method was very good, in some respects, where the total number of students was small and where they were all able to receive ordinary Morse signals at a fair speed. They not only had the benefit of the code practice but they also had some practical experience in the adjustment of detectors and in tuning, which is, of course, a valuable part of an operator's training. On the other hand where students are depended upon to get their own practice in this way, they are very apt to waste a great deal of time and their progress is slow.

In the spring of 1913, the Department of Commerce regulations went into effect, calling for Continental code and examinations for licenses. It was evident that numerous changes would have to be made in the course of instruction in order that the students might receive the necessary and proper training. As a result a complete reorganization of the department was inaugurated. The Continental code is now taught exclusively in the Radio Department and the system used for many years in the Morse work is followed with the exception, of course, that all receiving is done with telephone receivers instead of by means of a sounder.

Ten code circuits, operated at various speeds, are used at the present time. On circuits 8, 9, and 10, which are the beginners' circuits open buzzers are used. An instructor sends letters singly on the lowest of these, and the student calls out the letter as he recognizes it. The student is not permitted to copy on paper at the start as it is found that he then invariably loses interest before he has accomplished anything. There is always

a little rivalry among the members of a group of new students as to which one will be the first to call off the letters as they are sent; and this urges them to use increased energy in mastering the first few days' work. As they become familiar with all the letters, figures, and characters prescribed for radio signaling the students are advanced to a higher circuit where they pronounce words. Inside of a few weeks or less, they are able to receive words sent at a rate of four or five per minute. The length of time required, of course, depends upon the natural aptitude of the student, and his application.

Figure 1 shows the general arrangement of the code and lecture room; the photograph, being taken from the instructor's desk does not, however, include the switch board and instruments

FIGURE 1

used in controlling the circuits. On circuits 1 to 7, all receiving is done thru double head telephone receivers similar to those used in commercial working. The transmitter or signal producing device used on all of these circuits consists of a buzzer, controlled by a telegraph key, having line wires connected to the terminals of the interrupter, a condenser being interposed in one or both of these. On circuits 3 to 7, there is one transmitter on each circuit, with telephone terminals bridged across the line wires for seven students. Circuits 1 and 2 are arranged in long

lines along the side of the code room, and each is divided into eight stations all of which are equipped with a buzzer transmitter, condenser and transfer switch for changing from sending to receiving. All of these circuits are connected with a Western Union switch board at the instructor's desk by means of which any one of the circuits may be connected with any other or any transmitter on the instructor's desk can be instantly connected, by means of a loop pin with any circuit. Or, in the same manner, a telephone transmitter may be connected with any circuit. The code speeds on circuits 7 to 1 are gradual variations from five or six words per minute on 7 to the highest speeds on circuits 1 and 2 which usually are connected together. Each of the buzzers on these circuits is separately adjusted so as to give out as good a note as possible, and it always happens that there are as many different tones as there are buzzers inasmuch as it is difficult to obtain a perfect tone from all. This I consider to be an extreme advantage, however, over the system used in some schools where one master vibrator or other audio frequency generating device is used as a source of power to supply all circuits. It is possible for a student to become so familiar with one spark frequency, especially if it is absolutely regular, that he will have great difficulty in copying commercial stations which have sparks varying in a more or less degree from the perfect tone. With the individual buzzer method, however, an experienced operator, when listening in on our faster circuits to the interchange of radio messages will not fail to recognize its true ring. Some of these student stations emit a high musical spark resembling the 500-cycle stations, while there are others of varying pitch down to the rough irregular spark such as is emitted by the old low frequency sets of the Shoemaker type. In fact nearly every condition of arcing or other irregularity in a commercial transmitter is automatically met.

To some this may appear to be a deplorable way in which to teach a student to copy telegraph code, but on further consideration it is evident that the student not having had a perfect spark to copy from at all times, has accustomed himself to just the conditions of regular commercial service. Altho the tendency is toward a universal use of musical sparks and apparatus with which such sparks can be readily and easily maintained, it will undoubtedly be a long time before the difficulties of tone adjustment will be done away with. Again, the moral effect of an irregular or rough spark is impressed upon the mind of the student. Some students of their own accord endeavor to get and

maintain a clear tone, while others are more or less indifferent. In any case, the advantages of the good tone are evident and a certain pride is ordinarily taken in maintaining such tones. (I have been told by old operators that our students can be recognized by the adjustment of their test buzzers.)

Another advantage of the individual buzzer arrangement is that the loudness of the different stations can be readily adjusted to any fixed value, assuming that the frequency of interruption is constant. As previously mentioned, a condenser is interposed between either one or both sides of the line and the buzzer, and by constructing these condensers so that they have different capacities, their impedences are different and hence different stations can be made to send out signals of different strengths. Some of the stations have adjustable condensers and hence have a ready means of "varying their power." At the instructor's desk, variable condensers are used so that the signal strength can be varied from just audibility to any desired value. Other methods of varying the signal strength in such circuits readily present themselves, but the method outlined above has proven to be the most satisfactory of any that I have tested. In any case it is exceedingly important that the practice signals be not too loud and it is desirable to have them of different strengths. It has been my experience that a student may become so proficient in the code work on the circuits, that he can copy the most complicated code and cipher messages from the fastest senders, but when placed in the radio receiving room he will be able to get but little of what is being sent. This is partly due to the fact that he may be practicing with too loud signals. Ability to read very faint signals from distant stations is largely a matter of ear training and for this reason it is desirable to have the practice signals quite weak. On the other hand, an operator who is accustomed to receiving such signals may become so confused by very loud signals that he will be unable to copy them.

Each station on circuits 1 and 2 is provided with four calls; that is, it represents four different ship or land stations and the operator at each of these places is expected to answer any one of these calls. Inasmuch as the international call letters assigned to commercial stations in this country, into the service of which most of our students go, are combinations beginning with W or K, each of the student stations has one call beginning with each of these letters. The two remaining calls are selected from those used in the United States Naval service or foreign stations, thus

giving a wide variety of combinations. Some of these calls are selected on account of the difficulty encountered in transmitting them, or again there may be two that are easily confused or wrongly interpreted by a receiving operator. Others admit of a rhythmical swing which experienced operators develop. Among the different stations and ships represented on these circuits are those at the principal ports on our sea coasts and on the Great Lakes and the vessels which are likely to be in communication with them. The instructor's desk answers to or uses any call not assigned to one of the student stations. Occasionally the entire system of calls is changed. It is thought that such a system as this trains the student to be quick to recognize as well as to send difficult or uncommon calls.

Practically all the code work on these faster circuits consists of message work, and such other communications as are actually carried between ships and radio stations. Everything is carried over these circuits in accordance with the provisions of the London Convention, the Marconi traffic regulations, and good judgment. Students are not permitted to converse over the circuit nor to carry on any conversation except where the exigency of the case demands it. Messages are sent from one station to another with proper prefixes and service instructions, being relayed where necessary and filed for future reference. As might be expected, a student is often tempted to give an O. K. on a message addressed to his station when a goodly portion of it is missing rather than to ask for a repetition or to say that he had not received it, and in order to circumvent this, nearly all the messages sent out from the instructor's desk are messages that call for answers or must be relayed. This proves to be a very satisfactory method of insuring that the communication has been actually received and soon the student ceases to commit such offenses. Sometimes a wrong check is purposely affixed to determine if the student will note this. The various ship stations send in their "T R" reports and positions which must conform to the practice of commercial stations; in fact, everything is handled as nearly in conformity with actual conditions as possible. Very little press is sent over these circuits as it not only gives the student a fictitious idea of his ability, but really furnishes little practice. In fact, I am convinced that it has a tendency to make him "guess" more than anything else, which is, of course, one of the worst habits that an operator can acquire. In case such material is sent over the circuits, it is generally an article having in it many uncommon words. In some instances

subjects in French, German or Spanish, or long lists of code or cipher words are sent in an endeavor to train the student to write down just what he receives, by sending such material that he is unable to form any advanced ideas.

Another failing common to many operators, which we have endeavored to overcome in our men, is the inability to read signals thru interference. There always has been more or less of this to contend with, but now that all commercial work is ordinarily carried on at the same wave length, or at best at a few wave lengths the confusion has become greater; and when severe atmospheric disturbances exist in addition, it taxes the ability of the operator to the utmost. The acquiring of ability or skill in reading signals under these conditions is a matter of patience and concentration of the mind on one particular tone; a faculty which can be developed by training. In order, in a measure, to duplicate the condition of interference and to bring out this faculty of copying under adverse conditions, I make it a practice at times to have an interfering transmitter, or possibly several, working on the same circuit at the same time the regular code practice is being carried on over this circuit. This is done an hour or so each day and the results are exceptional. Ordinarily an omnigraph or other automatic transmitter is used to operate the interfering buzzer, the strength of the signals being variable. However, at times two groups of students will be carrying on communication simultaneously on the same circuit.

For the regular code practice, no automatic transmitters or sending machines of any kind are used, altho we have a number of varieties; except that a day or two before the government inspector visits the school, the omnigraph is used in order that the applicant shall not be confused by its mechanical accuracy. Hand sending by expert radio operators is depended upon entirely. All students receive such instruction either one and a half or two hours per day depending upon which circuit they happen to be working and the state of their advancement. During such periods of the day as there is no instruction on the circuit the students send among themselves, each being assigned a certain part of an hour, the schedules being rigidly maintained.

It is generally considered that not all men can become expert senders, this being a natural qualification with some; but it has been our experience that nearly any person can become a good sender if he is taught the full arm "pump handle" movement and rigorously practices it. Slow sending, if heavy, distinct, and properly spaced is always better than light rapid

sending in the case of a new man. After he has once become a good sender, he easily acquires the speed which is essential in many cases. Taking operators as they are ordinarily found, better speed can generally be made and more business transacted in the same time, by sending good distinct characters at a speed of twenty or twenty-two words per minute than can be done by transmitting at a speed of twenty-eight or thirty words per minute. There is always a tendency for new men to endeavor to "burn up" some other operator by rapid sending and if he is a poor sender at best, a great deal of time is lost as a result. Our code circuits are fitted with good telegraph keys, some Western Union keys, and some heavier keys similar to those frequently found in radio stations; and students are urged to practice a correct method of sending on these during all their spare moments. In cases where a man is especially stiffened in the muscles of his forearm from manual labor, or in other cases, we insist on an hour or so of continuous sending every day. After a student has practiced a correct method of sending until he has become sufficiently competent to transmit signals clearly, accurately and without "breaking," he is allowed to operate the school station on field days. Students are always anxious to do this but good sending on the practice circuits is pre-requisite. In most cases a good sender is the result.

In the technical or theoretical phase of the work the first part of the course consists of a study of the elements of electricity and magnetism, emphasizing such points as relate directly to radio apparatus and abreviating such matters as are not of first-hand importance. Following these more elementary subjects, the course is extended into a study of dynamo electric machinery, going only briefly into the theory of such apparatus, but giving special attention to the actual principles of the generation of current, the factors influencing the output, the function of the various parts, as well as the use, and care of such machines and methods of making tests and repairs. In connection with the study of alternating current machines the student is familiarized with terms common to alternating current operation (frequency, wave form, power factor, etc.), so that when the study of capacity and inductance has been taken up, the elements of alternating current problems will be less difficult. To facilitate the study of dynamo-electric machinery, the laboratory is equipped with a number of types of motor-generator sets used in radio service as well as various other A. C. and D. C. motors and generators of different capacities, together with starters, rheo-

stats and other auxiliary apparatus. Figure 2 is a view of the general laboratory which shows some of this equipment. In the foreground is a direct current generator, belted to a three-phase

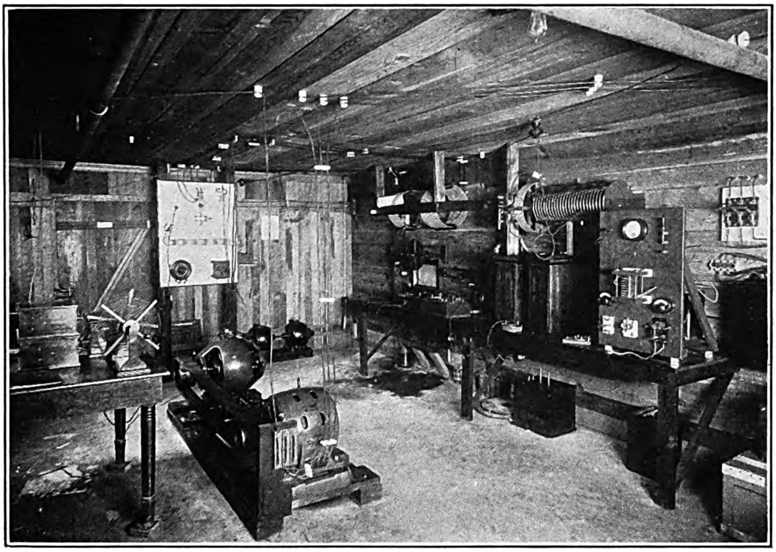

FIGURE 2

induction motor, the set being used to supply direct current for operating the motor-generators and other direct current apparatus. The generator of this set is of very open construction and the terminals of all windings are brought to a connection block, making it a very convenient machine for demonstration work. Along the right hand side of the picture can be seen several radio transmitters, of different types, used for instruction and demonstration work. Along the wall to the left, not visible in the photograph, are cabinets containing various kinds of physical and electrical instruments, tuning devices, measuring instruments, and other apparatus useful in experimental work in radio telegraphy.

After completing that part of the work covering dynamo-electric machinery, a study of electro-magnetic induction is taken up, theoretically and experimentally. This is one subject upon which too much time cannot be spent and every effort is made to present the phenomena of inductance and self and mutual induction in such a manner that the student will get a clear conception of principles involved. The effects of self inductance

are discussed in their relation to the primary circuits of induction coils and transformers. In the explanation of mutual induction I have found the use of audio frequency currents, generated by a buzzer, very helpful, using induction coils or coupling coils in which one of the coils can be rotated with respect to the other. Use is also made of coupling transformers of all types common to radio service, the result of which is that the student looks at the principle rather than any one form of construction. Many other schemes used by instructors in physics can be used to advantage. This part of the course is concluded with a study of the practical construction of commercial induction coils and transformers such as are used in radio installations, here as elsewhere, attention being drawn to methods of testing and making temporary or permanent repairs.

Following this work the next part of the radio set that is studied is the condenser, it being considered in its various forms and constructions. An effort is made to give the student a clear insight into the principles which are involved in certain important phenomena. Methods of calculating the approximate capacities of different types are shown, and then the means of obtaining any desired value of capacity, with definite dielectric strength, by the combination of standard units is demonstrated. Emphasis in this case is laid on the methods by which the proper capacity in the condenser of a radio set can be obtained by re-arranging the separate units of the condenser which has been injured, thru breakdown or puncture, and the precautions which must be taken in thus using it. Methods of charging condensers as used in the closed circuit of transmitters and the necessity for and function of the spark gap are demonstrated; which leads to a study of oscillatory discharges.

It has been my experience that unless the theoretical work is varied or made attractive by the interposition of actual radio telegraphing, thus giving an actual demonstration of some of these theories, it often happens that the student will lose interest, with the result that he fails to grasp the very things which are most essential. At this point, then, a horizontal aerial is strung up a short distance from the ground thus constituting a very apparent air condenser, and an induction coil is connected thereto forming a plain aerial transmitter. With this arrangement signals or messages are sent to portable stations. Altho this type of transmitter is generally known to the student, the experiment proves an interesting diversion in which many of the practical difficulties encountered in the operation of such sets

with large induction coils, and their remedies, can be easily demonstrated and in a forcible manner.

Just at this point, when the student has in mind the oscillations of the current in this plain aerial transmitter and the radiation of electric waves, I have found it to be a very opportune time to go ahead with the explanation of the terms period and frequency, and their relation to wave length. With an aerial 100 feet long, all of which is visible, the student can be made almost to see the oscillation running out to the end of that wire and returning in a given time, and if the wire is longer that it will take a greater length of time for the complete oscillation.

After concluding the study of plain aerial transmitters, with stress laid on the limiting quantity of charge that can be converted into radio frequency energy in consequence of the small capacity of the aerial, the work naturally leads into the study of coupled transmitters wherein much larger capacities can be used. With an understanding of oscillatory currents already acquired, the effects of the constants of the closed circuit on the wave length are quite apparent. I have found that a study of wave lengths in a circuit which does not radiate waves, leads to much confusion and lack of understanding hence the reason for a consideration of wave length in connection with the plain aerial transmitter first.

During that part of the work covering closed circuits of the transmitter, I assume a circuit having a condenser of a certain capacity about which is shunted an inductance of some twenty turns. It is stated that the wave length using say two turns is 300 meters. The inductance of the helix per turn is then calculated, and the results tabulated. The student then calculates the wave length with the movable clip on each of the twenty turns and enters this data in his tabulation after which attention is invited to the fact that the wave length varies as the square of the number of turns. From this it is apparent that in case he was working on a ship and for any reason was required to change his wave length say from 300 to 600 meters the position of the clips would be instantly known, with fair approximation, without the use of a wave meter or other device. In like manner, the effect of the condenser capacity on the wave length is demonstrated; and cases are assumed wherein a portion of the condenser is damaged and the use of half of the condenser with a definite increase in the inductance will give the wave length required, this to be obtained without the use of measuring instruments. It is a well known fact that the majority of operators,

after having once located a 600-meter adjustment on their receiving tuners, actually do very little tuning, and in case of accident to a ship or its radio equipment, it is very necessary that the operator on such a ship should be able to maintain his apparatus in such a condition that he can send on a wave very nearly 600 meters in length. In cases where the distance is great, this may be of extreme importance. Close coupling will not answer in all cases and hence an endeavor is made to give the student a knowledge of the best and quickest way in which to meet such conditions (to say nothing of the value which such information is to him at all other times). In order to verify the calculations and to bring the facts more emphatically to mind, the wave length at each adjustment is measured in the laboratory by means of a wave meter and the results are tabulated along with the calculated values in the note book which every student keeps. The results of such measurement are also reproduced in curves.

Following this work, means for transferring the oscillating energy to the radiating circuit and the conditions under which the greatest current is produced in the antenna are taken up and explained. Various methods are demonstrated in the laboratory for indicating the maximum antenna current, so that an operator will have some way of determining if his antenna is radiating the maximum amount of energy whether he has an approved hot wire ammeter or not. In the study of resonance between an oscillating circuit and an oscillating E. M. F., no attempt is made to avoid the actual alternating current principles which determine the strength of current that will flow in a circuit containing resistance, inductance and capacity. Once this idea is formed in the mind of a student a great many questions such as resonance phenomena in the audio frequency circuits, the use and proper capacity of telephone condensers in receivers, etc., are readily understood. In any case of this kind, the general theory is explained and then demonstrated by experiment. After demonstrating the tuning of the open and closed circuits in different ways the effects of re-transference of energy between them and the production of two wave lengths are brought out. Here, as in many other cases, it is necessary to exaggerate the fact in order to make the desired impression, and for this purpose we have some special apparatus with which it is possible to produce two wave lengths differing from each other by several hundred meters, with the two circuits tuned to an intermediate value.

At this point we take up the study of spark gaps especially

the quenched gap which, when placed in the primary circuit of the above coupled system, serves to demonstrate the quenching action in a forcible manner. I have constructed a small quenched gap having ten sections which quenches perfectly operating on 60-cycle current in connection with a one-fourth kilowatt leakage transformer. An attempt to measure the wave length of the circuit in which it is contained shows a very flat wave having a decrement that is difficult to determine. This is shown mounted on a small panel set (Figure 2) which was built for some experimental work in transmitting on low antennas.

The work in transmitting sets is concluded with a study of several standard sets that are in commercial use, showing the inter-relation of the various parts and auxiliary apparatus such as meters, circuit breakers, antenna switches, etc. One of the sets that we have permanently installed in the school is a Marconi 2-kilowatt, 240-cycle set which was loaned to us thru the courtesy of Mr. John Bottomley. This set is complete with storage battery-induction coil auxiliary set, and receiver. Several other complete sets of composite type are also installed. Figure 3 is a view of the radio station showing the Marconi

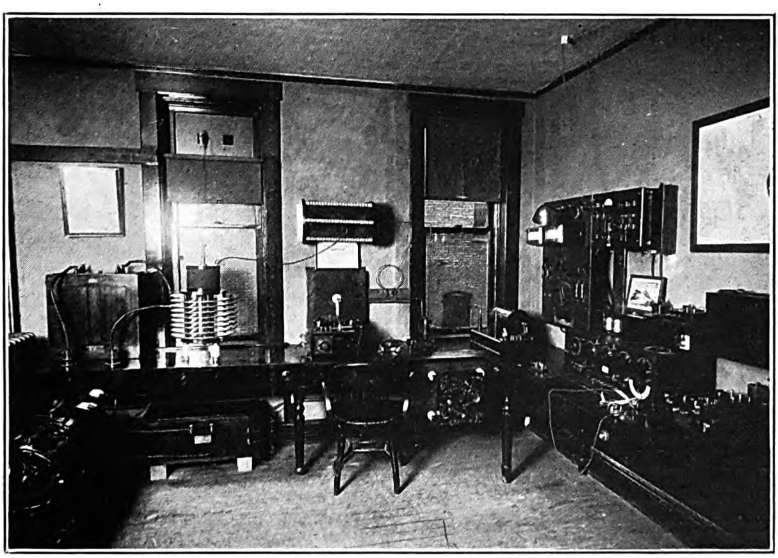

FIGURE 3

2-kilowatt, 240-cycle transmitter, the storage battery auxiliary transmitter, switch boards, and various types of receiving apparatus.

During the course, about one week's time is spent on storage battery work in which are set forth the details of types common in radio service, their care, methods of charging, etc. Some circuits applicable to emergency ship lighting are also shown.

In taking up the study of receiving circuits and receiving apparatus, we begin with a review of the principles of resonance, again emphasizing the factors which determine the impedence; wherein it is seen that the alternating E. M. F. produced in the antenna by the passage of a wave train can only produce a maximum current in the antenna to earth circuit when the inductance and capacity of that circuit bear a definite relation to each other. Therefore, in order that this circuit shall be adjusted so as to have a low impedence, its capacity and inductance must be made variable by the insertion of a variable condenser and a tuning coil at its earthed end. Before progressing farther into the theory of tuning, it is necessary to consider the action of some detector, such as a crystal rectifier, stating its function and the actual reason for its use. After this has been done, a detector can be included in our antenna circuit and we have the elements of the simplest form of receiving circuit. It is shown experimentally and theoretically how this circuit can be so adjusted that it will respond to waves of widely differing length; and then how it can be further adjusted so that it will respond only to frequencies which are very near to that to which it is tuned. Such a receiver is then compared with a standard receiver as to selectivity and strength of signals, which readily demonstrates its disadvantages. The next improvement on this simple outfit, the close coupled tuner is taken up in the same manner, theoretically and experimentally. In connection with this type of receiver, reference is made to commercial tuners embodying this principle, such as the Type "D" tuner of the United Wireless Telegraph Company, many of which are still in use. Every student, tho generally much to his displeasure at first, is required to use one of these tuners in the radio receiving room until he becomes familiar with its use and possibilities.

After the study of closely coupled receiving sets, and the various methods involving a direct coupling, their advantages and disadvantages, loose or inductively coupled receivers are taken up; first in an elementary way, and then in connection with regular receiving sets. Our laboratory is well equipped with tuning apparatus of various kinds so that quite an opportunity is offered for setting up any standard circuit, or most special circuits. Specific instructions in the use of commercial tuners,

such as are used by the commercial companies, follow the theoretical circuits. A great many operators in commercial service are incapable of getting the most out of their receiving sets; and especially is this true in the case of some of the more complicated receivers involving intermediate circuits or special tuning apparatus. In order to train the student to make the most of the facilities at hand and to give him an actual knowledge of the use of such apparatus, I have used the following scheme with success. The tuner or receiving circuit under test is connected to an antenna in the usual manner or to a dummy antenna in which are induced sharply tuned oscillations from a wave meter excited by a buzzer operated by an omnigraph. With the wave meter in operation, the student adjusts the receiver as broadly as possible, thus picking up the signals; after which he tunes for selectivity, and readjusts for the optimum results. After he has become familiar with the various adjustments several wave meter transmitters differing more or less in wave length are simultaneously operated, all being inductively related to the antenna or dummy antenna. A student will send with one of these transmitters while the one manipulating the receiver will endeavor to separate his signals from the interfering signals. In a short time the student becomes quite adept in tuning, and is able to meet many of the difficulties encountered in practice.

In the study of detectors, many of the common types are included, tho the most emphasis is laid on those of the crystal rectifying type inasmuch as they are the ones most used in commercial service at the present time. A great deal of stress is laid on the use of carborundum, which is probably more used and more reliable than any other detector. In much the same manner that a student becomes apathetic toward the Type "D" tuner, he becomes averse to the use of carborundum for reasons which are well known, but if he is supplied with a suitable potentiometer and a large collection of these crystals, he can generally be convinced that this form of detector has some merits. Every student, during the course, spends several hours testing crystals. The laboratory is equipped with a large number of detector stands, potentiometers, and tuners fitted for the use of these crystals, and in using these he gains an idea of the correct method of using such detectors, and eventually has more confidence in them.

One forenoon each week, a special class is held at which all students in the radio work are in attendance. This period is devoted to the discussion and study of radio law, the international

regulations, traffic rates, method of computing charges, and similar matters. On some occasions, classes in geography are held at this hour, and maps of the radio districts are studied, steamship lines and routes pointed out, location of radio stations noted, and so on. Each student is required to learn the name of every passenger steamship line on the Great Lakes, the names of their vessels, their runs, call letters, and stations with which they are likely to be in communication. This information is of great value to a new operator, and requires very little time to learn. Some students take a great interest in this work.

Altho our station license is an experimental license and calls for no specific hours of service, we have certain hours during which we always have one or more men on duty in the receiving room, where they get a great deal of practical experience. The requirements as to the matter of maintaining a continuous watch during the time that is assigned to a student are strict, the result of which is that the man acquires a sense of duty so that he is much more apt to realize the importance of his position after he is actually in the service. A complete log is kept of everything that transpires, and all messages are copied and filed. These later are sorted out and entered on report blanks such as are used by the commercial companies and which are furnished by them for this purpose. In fact, the business of the station, in every particular, is handled by the students in a manner as nearly in conformity with commercial practice as is possible. In rating students for positions their record in the receiving room, and number and completeness of the messages copied are taken into consideration.

The receiving room is well equipped with commercial tuners and some special receivers and other receiving apparatus. In the laboratory we have apparatus for receiving undamped, continuous wave stations as well as spark stations, and tuning apparatus for waves as long as 14,000 meters. Most of the equipment in the receiving room is commercial apparatus, while the experimental apparatus is used in the laboratory station. Figure 4 is a photograph in the laboratory receiving room, showing some special receiving apparatus used in research work. At the right is seen a long wave receiving coupling and on the left is a continuous wave generator which was built for testing receivers for undamped waves. It can also be used as a generator for heterodyne receiving. A radio-telephone, with which some experimental work has been done, can be seen in the foreground

on the left. Any transmitter in the laboratory can be controlled from this room.

For the regular station work, we have a standard six wire aerial, supported on a 100-foot (31 meter) steel tower, brought down to a mast on the building. In connection with the labo-

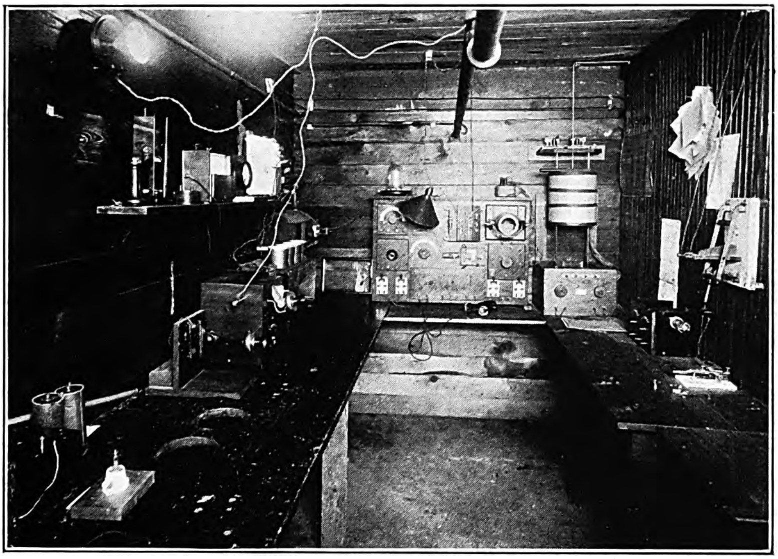

FIGURE 4

ratory apparatus, we have a smaller four wire aerial and a long single wire antenna, used principally for long wave reception. With the arrangement of these different aerials and certain apparatus, it is possible to have several groups of students receiving simultaneously without mutual interference. Ordinarily we have two well-advanced operators on duty in the station from 8 A. M. until midnight; however, in case of severe storms over the lake region, a continuous watch is maintained.

Another interesting feature of the work in the radio course is the so-called "field work." One afternoon each week, when the weather conditions permit, the students are divided up into parties of four to eight and supplied with portable receiving sets or complete field sets which are taken out into the surrounding country and set up. Aerials are erected on poles provided for the purpose or put up on high trees. Occasionally a kite will be used to elevate an aluminum wire or a small boat on one of the nearby lakes will be equipped with a small sending and receiving

set. Figure 5 shows a field station, in the charge of a group of students, with which they are in communication with the station at the school. As will be seen this set includes both transmitter and receiver, and when the aerial is elevated to a suitable height,

FIGURE 5

it has a range of several miles. It can be used either as a "plain aerial" set or directly coupled, radiating about half an ampere either way when properly tuned.

Communication is established between these field stations and the school, where an operator is maintained. During the course of such work aerial construction, methods of quickly putting up an emergency aerial, and the importance of good earth connections are demonstrated in an interesting and forcible manner. I have also found this to be an excellent manner in which to combine practical detector adjustment, tuning and wiring up of apparatus. Many interesting experiments that can be performed in the open country readily present themselves, all of which are of advantage in an operator's training. The effects of broad and sharp waves, necessity of tuning, and the

advantages of high spark frequencies and so on are readily set forth in an interesting manner.

For the benefit of special students or those who are particularly interested, we have a somewhat more advanced course in electrical and radio engineering subjects including radio telegraphic measurements and theories. The extent of this work, at the present time, is limited owing to a lack of necessary equipment, but at the same time it offers some advantages to those students who are ambitious and desirous of extending their knowledge of the art of radio communication.

During the coming fall it is our plan to erect a second steel tower 175 feet (54 meters) high at a distance of 400 feet (123 meters) from our present tower. It is also expected that we will add considerably to our electrical equipment at that time.

**SUMMARY:** The qualifications of a "good" operator are divided into inborn and acquired or teachable characteristics. A course of training for radio operators is then discussed in detail. The entrance requirements and objects of the students are considered, and the subject matter of the course is given.

1. OPERATING DIVISION. Students are taught to receive on buzzer-excited circuits, using head band telephone receivers. A number of circuits of gradually increasing speed and difficulty are provided. Different tones and intensities of signals are provided to accustom the student to actual conditions. All messages sent between student stations are in accordance with the radio laws and commercial practice. Messages must generally be checked and relayed by the student. Artificial interference is provided to teach reading of desired message thru such interference.

2. TECHNICAL DIVISION. The elementary principles of electricity and magnetism and the study of dynamo-electric machinery are given. Inductance, mutual inductance. capacity, wave length and frequency are studied, together with methods for their predetermination by calculation. Resonance phenomena are shown. Different types of commercial receivers and crystal detectors are tested. Field work is done with portable transmitting and receiving sets. Some facilities for research work are provided.

3. TRAFFIC DIVISION. The radio law, international regulations, geography and other material of value to operators are taught by lecture. Work in penmanship is obligatory.

## DISCUSSION

**Elmer E. Bucher:** After careful consideration of Mr. Packman's contribution, I see that he recognizes the time-worn but desirable search for the "one hundred per cent perfect" employee. To a slight extent, I agree with him that in some respects the efficiency of the operating staff of commercial radio telegraph companies might be improved; but I must take complete exception to the allegation that the training of operators has suffered neglect, or that progress in this detail has not kept pace with general commercial radio development. The further reference to "deplorable conditions," assumed to exist in the operating staffs at certain commercial ship and shore stations, cannot carry weight without citations of specific instances of inability. It is useless to decry the service or personnel of an entire organization for the disability of a few, hence it may be of interest to give a brief outline of the method of instruction in vogue at the various radio schools maintained by the Marconi Wireless Telegraph Company, thereby disproving the assertion that radio telegraph operators have not been well trained.

It has been the practice of that Company since its inception to instruct its employees thoroly in the subject of radio telegraphy by the establishment of schools both here and abroad. In localities where the demand for operators has been insufficient to warrant the opening of a company-owned school, local telegraph schools have been subsidized or supplied with apparatus free of cost. In addition, these schools have had the free services in an advisory capacity of the Marconi officials and engineers, who have thereby assured themselves that the graduated students possess qualifications suitable to a proper standard. The foregoing policy has been adopted and rigidly adhered to thruout these years, and it is a fact that the courses given at privately owned institutions have been generally modelled after that given at the Marconi training schools.

In general, corporation-owned schools have the advantage over privately owned schools in that the former are in possession of a more complete radio equipment and are thus enabled to offer their pupils a more comprehensive course than is otherwise possible. Being in closer touch with commercial radio development and the demands of a well organized radio service, such companies are prepared to supply their students with the knowledge most necessary to their requirements, technically and commercially.

A particular problem which radio schools are compelled to meet is the varied degree of intelligence and ability manifested by the applicant for admission. In a university or college, before a student is enrolled on the roster, certain conditions must be met and complied with; consequently it is assured that the entrant is, in a large measure, fitted for the instruction he is about to receive. More clearly, such applicants have thru a number of successive years gradually fitted themselves for their more advanced work, and are therefore able to derive the fullest benefit of the instruction.

Obviously, in a radio telegraph school, such a long drawn out procedure is not possible: first, because the applicant has neither the inclination nor the financial means to support himself over an extended period of training; and second, because no commercial company would care to meet the financial drain imposed upon its treasury by carrying a student on the register for a great number of months. It may be of interest in this connection to remark that corporation-owned schools are not generally a financial success; yet companies are perfectly willing to stand the expense involved in order to maintain a high standard of service by the employment of a staff of well trained men, so important to its commercial success.

Therefore, in order that the student may receive a permanent assignment in the radio service with the least possible delay, it becomes the duty of the radio telegraph school to fill in the gaps in the student's knowledge of the art. In consequence, it is not always possible to inaugurate a definite course of procedure. In so far as possible, the mode of instruction must be varied to meet the individual needs of the pupils.

So far the best success has been achieved by first ascertaining the knowledge of the applicant in respect to the radio art in general and the fundamentals of elementary electricity and magnetism. This known, we are at once enabled to segregate the students into two classes. The missing links of the more advanced student's knowledge are then filled in by a number of general lectures on radio telegraphy, after which a series of experiments are made on the actual apparatus.

The student least informed on matters of electricity is placed in a separate class where he is given thoro instruction in the elements of electricity and magnetism. Slowly but surely, the supposed complexities of the art disappear, the pupil having formed a complete mental picture of the underlying action upon which the operation of radio telegraph apparatus is based.

In this work the instructor must exercise great patience, for it takes time to shape and mold the thought of a raw recruit in the right direction.

A similar procedure is adopted in respect to instruction in the telegraph code; *i. e.*, the student's ability is first ascertained, and then a division into classes made accordingly.

In the code classes artificial radio telegraph circuits are employed thruout, traffic being dispatched from individual to individual after the method employed at commercial ship and shore stations.

The foregoing instruction is followed up by a series of lectures on "Radio Traffic" in which the student is fully informed on the International, United States, and Navy regulations. Intricate problems which the student may encounter in dealing with various radio stations of foreign countries are discussed and solved, until it is certain that the pupil is thoroly familiarized with all possible future conditions which he may meet.

Contrary to the views expressed by the speaker of the evening, I am in favor of introducing a certain amount of automatic machine sending now and then in the code practice, for it has been observed to have a marked effect upon the student's sending. A good automatic Wheatstone sender, connected to a buzzer system, and operated at a speed suitable to the pupil's ability, will do wonders in impressing upon his mind the desirability and necessity of a uniform mode of sending. The ease of reception experienced impels the student to adopt a similar mode of formation more or less unconsciously, resulting in daily improvement.

I would lay down no hard and fast rule concerning the time required for a student to complete his tuition in radio telegraphy. I do not believe it possible to make an expert telegraphist from an absolute beginner in the space of six months, even tho I am aware that this condition has been approached in isolated instances. I do, however, maintain that by six months' study and close application a student is qualified to pass the U. S. Government examination and competent to take an assignment as junior operator at any ship or shore station.

It might be mentioned here that the Marconi Company uses every precaution in introducing a beginner into the commercial service. It is its custom to send a school graduate to sea as a junior operator, under the guidance of an experienced man. In this manner he is enabled to derive the full benefit

of the senior operator's previous experience and all possibility of error thro lack of initiative on his own behalf is thereby eliminated.

In respect to training the student to read radio signals thru interference, a school located in a prominent seaboard city such as New York, does not require artificial "jamming" or interfering apparatus. A commercial receiver connected to a fair-sized aerial fulfills the requirements, the operator being enabled to separate interfering stations under actual commercial conditions. Obviously, no better method of training could be devised.

I note from Mr. Packman's contribution that certain pupils with whom he has come into contact possessed biased minds, even to the point perhaps of expressing their desires as to the type of apparatus they consider preferable! A student having pre-conceived notions in this respect is apt to possess proclivities along other lines not amenable to discipline. Hence I would lose no time, in extreme cases, for the good of the services, in eliminating his name from the records.

I contend that the profession of radio telegraphy requires young men of live and alert characteristics who are quickly capable of assimilating new ideas, progressive in their make-up and business-like in character. To secure a well-rounded employee, one equally proficient in several branches of a given art, is one of the problems of the hour; the natural result of this need has been an age of specialization which in many fields has been overdone.

A radio telegraphist cannot be a man of narrow vision. He must be broad enough to think in terms international for he comes in contact with peoples, business methods, and social customs, of all climes and races. Thru several years of experience I have not found it difficult to lay out a course of procedure that will fully fit the student in this respect; and I firmly believe that, in view of their previous training, the degree of proficiency attained by the average radio employee is remarkable, and that in no department of wire telegraphic or telephonic communication will there be found operatives of the attainments of the average telegraphist in charge of radio telegraph equipment to-day.

I think it will be found on investigation that as far as the Marconi Company is concerned, the training of radio operators has in nowise suffered neglect. Every possible available means has been brought to bear in the student's preliminary

education so that he may be fully qualified to meet any emergency arising on his initial assignment to a ship or coast station.

**David Sarnoff:** I consider that the radio operator is one of the most important elements in radio communication. I agree, in some respects, with Mr. Bucher's refutation of the statement made by Mr. Packman regarding "the rather deplorable conditions which exist at present in the radio operating field." I believe there has been a marked tendency toward improvement in this direction during the past few years, and observation justifies the expectation that the improvement will continue.

The acquisition of the late United Wireless interests by the Marconi Company, thereby placing the large number of radio operators under the control of one organization, and the international requirements that a single code—continental—be universally employed, have helped matters considerably. By having all operators under the control of a single organization, antagonism and rivalry among operators otherwise employed by competing radio or steamship companies are removed and this is a very important factor. The advantages of a universal code are obvious in that it renders communication between operators of all nations more flexible.

Before operators are employed in the Marconi service, they are required to pass thru the Marconi School of Instruction where they are given thoro instruction in the principles and manipulation of the various types of radio equipment in general commercial use.

The procuring of a government radio license is not considered sufficient proof of the operator's ability and general fitness for the Marconi service. There are of course exceptional instances where deviation from this rule is imperative and under such conditions the choice of an operator must be governed by the exigencies of the moment.

I should like to say a word or two about the training of the radio operator, starting from the point where Messrs. Packman and Bucher leave the subject.

In my opinion the actual training of the operator commences after he leaves school and joins the operating staff. I have frequently thought that the present method of employing graduates from radio schools in the radio service is wrong; for the reason that at present their first positions are given them on shipboard whereas the better way would be to assign them

first to coast stations, where they would obtain the benefit of the more skilled operators on shore, who are thoroly familiar with the proper methods of conducting radio traffic. Here also, the novices in the profession have a better opportunity of handling a larger amount of radio traffic, under the guidance and with the assistance of the more matured and trained coast station operators. The early Marconi operators, and those who now hold the more important positions in the organization, were thus trained.

Unfortunately, however, my theory is not possible of adoption by radio organizations at present, for the following reasons.

First. Because the number of coast stations now in operation, as compared with the number of ship stations, is proportionately very small.

Secondly. Because the majority of the coast stations are situated in out-of-the-way places where, by reason of existing circumstances, it is not practical to assign any but trained operators.

Thirdly. If a graduate from a school is sent to an important coast station and spends some time in becoming proficient, it is hardly to be expected that he would thereafter view with favor the assignment to a less important position on shipboard. Here, too, the difference in salaries paid at ship and shore stations would play an important part.

It is interesting to note from this evening's paper the different methods employed in training the student to become a proficient radio telegraphist, but experience has taught us that there is a marked difference shown by the young operator in transmitting or receiving messages in school, and in handling regular business at a commercial station. This is but natural, and a condition which must be expected. It is for this reason, however, that the disadvantages of placing a school graduate, even on an unimportant freight ship, are so apparent. One poor operator on shipboard, with even a weak radio equipment, can do more harm when in the vicinity of busy ship and shore stations, than can be undone by ten good operators, with an equal number of efficient sets.

In the paper on "Radio Traffic" which I delivered last year before the Institute, I dwelt at length on the importance of brevity in radio communication, and this all-important point cannot be impressed too strongly, especially on the young operator. Very often I have observed junior operators assigned to less important ship stations, transmitting a radiogram by

the longest method possible, inserting unnecessary symbols and words, repeating where there is no need to do so, and thereby retarding the movement of traffic very seriously.

The young operator is often actuated by a desire to listen to himself sending. On ship stations where traffic is infrequent, the junior operator often indulges in quite a lot of unnecessary preliminaries and finishing touches, when transmitting or receiving a single message. While these matters may appear insignificant to some of those present, I submit that you need only consider the unfavorable conditions of static, or strays, interference, and frequently poor operating, to appreciate what it means to indulge in superfluities under such circumstances. On the other hand, the advantages of brevity under these conditions will likewise be apparent. Unfortunately, the government regulations pertaining to radio communication, are not adapted to the solution of these practical problems when they prescribe certain preambles and symbols in handling radio traffic. In my paper on the subject previously referred to, I gave examples of this condition.

I also reiterate my long-standing objection to the present wave length regulations enforced by international agreement. It avails us very little to produce transmitters of high radiating efficiency, and receivers capable of sharp tuning, when the majority of ship and shore stations employ 600 meters as their working wave length. I am aware, of course, that wave lengths below 600 meters may be used, and while this has been taken into consideration in the design of the more modern equipments, it fails entirely, nevertheless, to afford the measure of relief required.

In this connection I might say a word or two in admonition of the operators who fail to take full advantage of the opportunity afforded them by the latest Marconi equipments, which are provided with 300, 450 and 600 meter wave lengths, and with facilities for rapidly changing from one wave length to another, the change being effected by the throwing of a single switch. I have known operators who continue to struggle thru interference on 600 meters rather than change to 300 or 450 meters, and I have also observed others who do not even struggle. It is, however, not possible, under the present government regulations, to take full advantage of even the wave lengths mentioned; for the reason that by the rules of the London Convention it is required that when two stations communicate, both must employ the same wave length. Therefore,

while it is feasible for a ship station equipped with the latest Marconi set to change quickly from 600 to 450 or 300 meters when communicating with another ship or coast station, it is not quite so feasible for the coast station to effect the same change. You will appreciate, therefore, the importance of reconsidering the whole subject of wave lengths and traffic regulations.

I would urge all of you who have opinions to express on this subject, to write the Institute.* It will be glad to accumulate and summarize all ideas so that a logical and comprehensive statement of facts and suggestions may be presented at the next International Convention, which is to be held at Washington, D. C. It may sound a trifle optimistic to talk of International Conventions in these days, but we are hopeful nevertheless.

In connection with the proper manipulation of radio equipments by operators; I have noticed during my experience that radio engineers are very often prone to criticize the operator for failure to obtain maximum efficiency, and I doubt not that the criticism is sometimes warranted; but on the other hand, something may be said about the radio engineer who, when designing radio equipment at the laboratory, fails to appreciate the operator's difficulty on shipboard. For instance, I have always felt that sufficient attention has not been paid by designing engineers to the subject of detectors. Sensitiveness seems to be the goal for which most engineers aim, but apparently stability is not given the same consideration. There is nothing more troublesome at radio stations than to handle a detector which is too frequently affected by vibration, induction from transmitting apparatus, or by the many other causes which disturb crystal detectors. Operators many times continue to call radio stations which promptly respond but are not heard because the detector at the calling station is temporarily out of adjustment. Every operator knows that this is a daily occurrence and the cause of unnecessary interference, repetition and consequent delay in the movement of traffic. I am of the opinion that some form of valve detector is probably most suitable for commercial operation at ship and shore stations, because the valve detector gives more promise of possessing the combination of the two important elements, namely, sensitiveness and stability.

* A paper dealing with "The Inadvisibility of Wave Length Regulation" will be delivered by Messrs. Goldsmith and Hogan later in 1916. All members having views on this subject are strongly urged to communicate them to either of the authors in writing.

As regards commercial radio schools versus radio telegraph company-owned schools: It is preferable, of course, where a student can do so, to take up his course of training in a school of a large radio organization, because such a school is conducted with the object of training the men for the company's service and not for the profit derived from tuition fees. But there are many cases where, for good reasons, it is not possible for a young man to attend the company's school, and for this reason the commercial schools are performing a very important mission in the radio art. Men must be trained, and they should be trained properly. Many a boy living at or near Valparaiso, Indiana—where the Dodge Institute of Radio Telegraphy is located—might have been unable to take a course in a Marconi School situated elsewhere, and for that reason the Marconi Company lends its support to, and assists in every possible way, this School, as well as all other schools which show a desire to train operators as they should be trained.

**Alfred N. Goldsmith:** There is no doubt whatever that the question of wave length regulation, which has been brought up by Mr. Sarnoff, is worthy of the most careful consideration. It is further desirable that it be carefully considered *at length,* in view of the possibility of an International Convention on this subject within the next two years. It is not at present obvious that wave length regulation is at all a necessity, and certainly the matter is one for considerable discussion.

As an illustration of an undesirable state of affairs, attention may be called to the restriction of the important range of wave lengths between 600 and 1,600 meters to the use of the Government. It will be noted that most of the stations using these wave lengths are Navy stations, primarily intended for use in times of war, but not for commercial service in times of peace. Whenever one realizes that in times of war the enemy would hardly refrain thru courtesy from using wave lengths within the restricted range, the valid objection to closing this range to all commerical ship and shore stations, becomes evident. The ability to tune skilfully and read thru interference is well worth cultivation.

I feel further that amateurs have been unduly hampered by the wave length restrictions which are now current. This, however, is of comparatively small importance when contrasted with the really serious crippling of commercial traffic by the enforced rules concerning 600 meter transmission and the equality

of wave lengths between ships and their corresponding shore stations.

I expect that in the near future a paper will be written by Mr. Hogan and myself dealing with the question of wave length regulation and considering critically whether any wave length regulation should be adopted, and furthermore what rules of radio traffic are most desirable. I am very desirous that all members of the Institute or others interested, should correspond with Mr. Hogan or myself, on this subject in order that we may have the broadest expression of opinion on which to base our own judgments.

Referring further to a possible part of the training of the radio operator which has not been clearly brought out, it seems to me that it would be well to give the students in radio operating some courses in reading messages thru atmospheric disturbances. It would be possible to imitate their effect in the laboratory and thus train the student, at least to some extent, in receiving thru such strays.

**John L. Hogan, Jr.:** I have been much interested both by Mr. Packman's paper and by Dr. Goldsmith's statement as to the problem of wave length restriction which has been before us for some years. It is so nearly a self-evident fact that the present Federal regulations as to radio wave lengths are of an unjust and ineffectual nature that their adoption seems a most surprising thing. The restriction of wave lengths between 600 and 1600 meters, which is the range best adapted for low and moderate power ship communication, to Government use is an act which has caused and is causing unfortunate delay in the development of the commercial radio art. The requirement that inter-communicating stations both use the same wave length, and the insistence that ships communicate always with the nearest land station, are also regrettable features of the present Convention rulings.

With reference to Mr. Packman's paper, I must agree with Mr. Bucher in his indication that the operating situation of commercial radio telegraphy is not entirely "deplorable." Nevertheless, there are a number of points upon which the vast majority of radio operators could be better trained.

One of these, which was mentioned incidentally by Mr. Packman, receives far less attention than it really deserves. This is the matter of operators' handwriting. It has been my experience that the "copy" of radio operators is as a rule much

poorer than that of wire telegraphers. One reason for this is, of course, that the average age of the radio men is considerably below that of the line men, and that the penmanship of the radio operator is therefore likely to be in a formative stage. Another reason is that the traffic in many radio stations, on account of its small volume, puts no especial premium upon and offers no especial opportunities for clear smooth handwriting. It is a fact, nevertheless, that a radio operator is not likely to advance rapidly to better operating positions, and thereafter to executive positions, if his handwriting is of an uncertain and illegible type. It is not probable that too much emphasis can be laid upon the desirability of careful drill in helping to form the habit of clear and characteristic handwriting.

A second point is that radio operators in a commercial telegraph school should be trained to copy signals thru static interference strays. I have known men to be graduated from telegraph courses with the ability to read good buzzer signals, at fairly high speeds, and after securing their Government licenses, to fail utterly in attempts to read incoming radio messages thru even moderate static disturbance. Until an operator has become accustomed to concentration upon signal notes in the midst of harsh irregular noises from strays, he is likely to become excited and useless if he encounters unusual atmospheric interference. If it were difficult to give such training during the usual telegraph course, it might be expected that the operators would have to wait until they entered commercial service for this part of their training. However, it is not at all impracticable to combine practice in receiving thru strays with the ordinary daily code practice which all students of radio operating must be given.

Figure 1 shows a device which is simple and easily set up, yet which I do not believe has been used for this purpose except by the National Electric Signaling Company. In this diagram, X represents a weighted pivoted contact which drags upon the heavily and irregularly knurled surface of a slowly revolving metal wheel. Connected in series with this imperfect contact is a battery $B_1$ and potentiometer $R_1$. By suitably choosing the speed of the wheel and the weight of the contact at X, the strength of battery $B_1$, and the position of sliding contact on $R_1$, irregular impulses corresponding to almost any sort of static may be applied to the line wires $L_1$, $L_2$, thru the telephone transformer $T_1$. These irregular current impulses, transmitted from the line wires, are reproduced in receiving

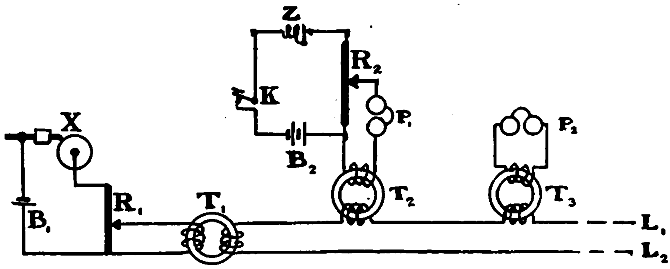


FIGURE 1

telephones $P_2$, thru the telephone transmitter $T_3$, as scratchy hissing sounds closely resembling those produced by atmospherics. A buzzer sender, consisting of a buzzer of any frequency Z, a key K and battery $B_2$, and a variable resistance $R_2$, may be associated with the line wires thru another telephone transformer $T_2$. By varying the potentiometers $R_1$ and $R_2$, the relative intensities of strays and signals can be made anything desired. It is, of course, obvious that additional transmitters of various frequencies and intensities can be associated with the same line wires, and that these wires may be used to conduct the signals to any reasonable number of student's receiving telephones, such as $P_2$. While many modifications of the device are obvious, the system as shown has proved very useful for such work as I suggest, and practice on it would form a desirable part of any radio operator's preliminary experience.

A third point upon which many radio operators are weak lies in the adjustment of their receiving tuners. Inductively coupled receiving apparatus, having variable primary and secondary inductances, and a tuning condenser directly connected across the secondary coil, represent the best practice of the commercial radio service to-day. This apparatus, simple as it is, is capable of giving widely different results in the hands of operators of different degrees of experience. Setting aside for the moment those men who are really able to handle an inductively coupled receiver properly, the remaining radio operators may perhaps be divided into two groups. The first of these, which we may call the "primary men," do all their adjusting by altering the inductance of the primary circuit and at the same time leave the secondary inductance and capacity at some average setting which gives fairly satisfactory results, so long as no interference is encountered, The second group, or "secondary men," have a great aversion to changing the settings

of their primary coils and tune only with the secondary variable condenser. It is obvious that an operator who is in either of these classes will be certain to get only mediocre results from even the most carefully designed receiver. It is highly essential that all radio operators should appreciate that with an inductively coupled tuner they will secure maximum loudness of signals with maximum freedom from interference when their primary and secondary are both tuned to the wave length they desire to receive, and when the coupling between primary and secondary coils is properly adjusted. It requires a considerable amount of actual practice with inductively coupled tuners to learn just how the four variables (primary, secondary, inductive coupling, and secondary capacity) are inter-related and how compensating adjustments in each must be made as the others are changed.

In order that beginners may have training of this sort, they are usually given short periods of listening at an operating receiving radio station. It is manifestly impossible to handle a large class in this way, giving each one of them enough practice in tuning to be of much value to him. In order that radio schools may deal with this point in a way comparable with its importance, I suggest the circuit arrangements shown in Figure 2.

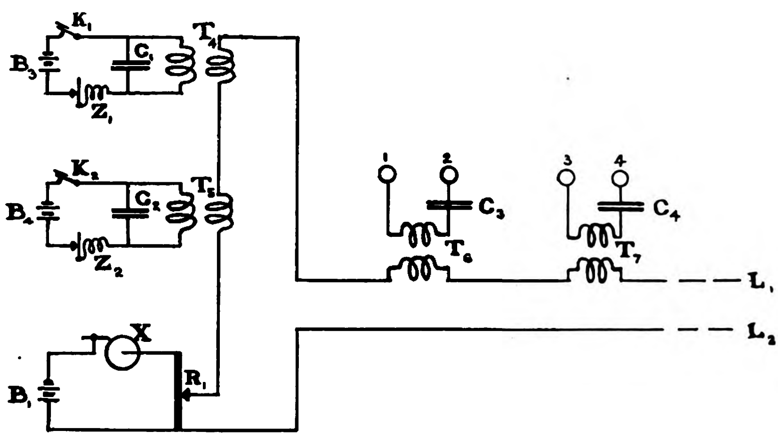


FIGURE 2

In this diagram, buzzer exciters producing radio frequency currents of any desired intensity and group frequency, and corresponding to waves of any length and decrement encountered in practice, are associated with the line wires $L_1$, $L_2$. The

buzzer Z is connected with battery B, key K, capacity C, and the primary air core transformer T as shown. With the same line wires a static exciter such as that described in connection with Figure 1 may also be connected. At each student's desk, the line wire is connected thru a transformer, such as $T_6$, which has its terminals connected to binding posts such as 1 and 2, thru a condenser, as $C_3$. The radio frequency currents set up by the buzzer exciters impress forced radio frequency voltages upon the terminals 1, 2, and if the capacity $C_3$ and inductance of $T_6$ are chosen so as to represent properly an average antenna, any radio receiving set may be connected to the two binding posts exactly as it would be connected to antenna and ground in a radio station. By tuning the receiving sets so connected, signals from any of the buzzer exciters may be selected, as signals from outside stations may be selected in practice. The difficulties of eliminating highly damped disturbances, such as those of strays, may also be experienced in this way, since the impulse maker X will shock the primary circuit of each receiving tuner into oscillation of whatever period it has, exactly as static would in an ordinary receiving station. For tuning to damped waves, one or more of the buzzer exciters may have resistance inserted in their oscillation circuits, so as to increase the decrement of the current impulses there generated.

Simple modifications of Figure 2 which will permit students to inter-communicate under conditions very closely approximating those of actual radio practice may easily be devised by following the principles just outlined. It is certain that training of this sort would go far toward increasing the traffic handling ability of any operator who has not reached a point of high efficiency in the manipulation of his instruments.

By these comments, I do not wish to be understood as inplying that radio operators in general suffer from inability in these several directions. There are many men in the field of whom their respective service executives may well be proud. There are, nevertheless, many inexperienced telegraphers who would be greatly benefited by thoro drill in the three matters I have discussed. It is my hope that future courses of training in radio telegraphy will give beginners greater opportunities for thoro understanding of commercial radio conditions.

**M. E. Packman:** In reference to Mr. Hogan's scheme of using many commercial receiving sets, which, of course,

is highly desirable, he apparently fails to appreciate the fact that it would require about 25 to 30 receiving sets, costing from two hundred and fifty dollars up. Such expense is not possible for commercial institutions.

The work with elaborate artificial antennas in receiving has been turned over to the more advanced students.

In reference to Mr. Bucher's and Mr. Sarnoff's remarks in connection with the deplorable conditions I referred to, I think that they are both considering the service on the Atlantic Coast which is indeed better than it is in other parts of the Marconi service. I am more or less familiar with Mr. Bucher's school and know that his training is very comprehensive but the point is that the demand is far greater than the school can supply. I have known men in service who have first grade licenses and who are actually unable to receive anything. I have known men in my own school who get thru the commercial examinations with no trouble who are practically worthless as far as commercial service is concerned. This condition has been the case for a good many years in the part of the work with which I am familiar, tho it has been improving from time to time. Many operators have been employed who have practically very little knowledge as compared with what they should have.

On the Great Lakes, it must be considered that the time of navigation does not exceed over nine months and that out of 60 or 80 ships, there are only 15 or 20 which run the whole year round. This means that there will be 40 or 50 operators required at the beginning of the season. Some of the old ones return, but only very few, and the first men that call at the office are the ones that secure the positions, regardless of their ability. The point to be noted is that they are employed without knowledge of the chief operator as to their ability. This condition does not exist in the East to this extent.

(Further material received from Mr. Packman too late for insertion in this issue of the PROCEEDINGS will appear in an early issue.—EDITOR.)

# SUSTAINED RADIO FREQUENCY HIGH VOLTAGE DISCHARGES*

By

Harris J. Ryan and Roland G. Marx

## INTRODUCTION

In high voltage work, discharges thru the air between conductors and over and thru insulators can be prevented only with the aid of ample knowledge of their characteristics. Discharges produced by low (audio) cycle voltages for given conditions are now fairly generally understood. In radio telegraphy, high (radio) frequency damped and sustained high voltage waves are employed. Accidents, including lightning, produce in high voltage power circuits, in the long run, almost every conceivable high voltage transient. Such transients may vary from a simple over-voltage at normal frequency thru all possible impulses and damped oscillations to perhaps a briefly sustained high frequency high voltage wave train. Little is known as yet of the relation between discharge distances and voltages of the various sorts just specified. The evidence so far accumulated indicates that for given values of maximum voltage, the discharge distances are almost *independent* of the characteristic variation of the voltage whenever the critical corona voltage is higher than the discharge voltage. It indicates, too, that the discharge distances are *dependent* upon the characteristic variation of the voltage whenever the critical corona voltage is below the discharge voltage. In regard to the latter condition, this evidence indicates further that the discharge distance will be longest when the voltage source or transient is most sustained, or when its frequency is the highest or when both of these characteristics are present. It follows that discharge distances should be found a minimum for low frequency high voltages and a maximum for sustained high (or radio) frequency high voltages. It thus appears that voltages which can be formed by accident may discharge thru

* A paper presented before a joint meeting of The Institute of Radio Engineers and The American Institute of Electrical Engineers, San Francisco, September 16th, 1915.

greater distances and do more damage than the same values of voltages as used in most commercial work. The following experiments were undertaken as a reconnaissance in this region of high voltage phenomena.

## DISCHARGE INTO THE ATMOSPHERE FROM A SINGLE ELECTRODE

One terminal of a sustained high frequency high voltage source[1] was grounded, the other was a 1-inch (2.5 cm.) copper tube capped with a hollow copper sphere 2 inches (5 cm.) in diameter. This spherical end of the high voltage terminal was mounted properly remote from all grounded objects. When a voltage of 50,000 at 88,000 sustained cycles was applied, a dry redwood stick was brought near to the sphere and then removed. A spark passed from the sphere to the stick and immediately grew into a heavy brush discharge. See Figure 1. It consisted

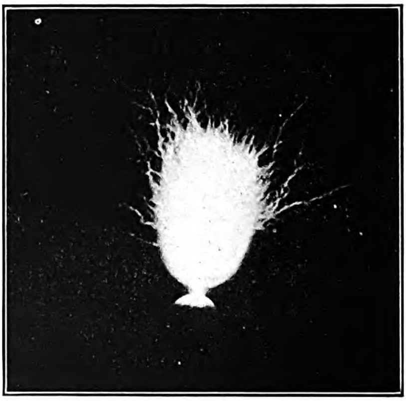

FIGURE 1

essentially of an active mass of darting streamers. The character of this mass varied from that of a combustion flame at the base to the familiar static discharge at the extremities. We have been able to determine with a fair degree of approximation (by measurement correct to within ten per cent.) that the rate of energy supply in the discharge from the electrode, illustrated in Figure 1, was about one kilowatt. It is charac-

[1] Described in "*Sphere Gap Discharge Voltages at High Frequencies*," by J. Cameron Clark and Harris J. Ryan, "Proceedings of the Am. Inst. Elec. Eng'rs," June, 1914, Vol. XXXIII, page 937.

teristic of this high voltage, radio frequency discharge, that it consumes a large amount of power; and if that power is not available, a discharge will not develop. It may start to develop and one may see some brush momentarily, but not the actual discharge. No "flashing-over" effect will be produced unless plenty of power is available. The discharge averaged about 10 inches (25 cm.) in length, was rather bright, produced a hissing, roaring sound, and was not accompanied by the familiar odor of ozone that is formed by the less violent audio frequency or intermittent radio frequency discharges. It is easily blown about by air currents. It may be blown by the breath from place to place on the ball. It can be fanned with a hat from the ball back along the 1-inch (2.5 cm.) conductor, and put out as it is driven into the region of lower capacity in the vicinity of the conductor, that is, where the fields are less intense and where the energy cannot be delivered at the rate that the flame or the discharge requires.

A modification of the above experiment was arranged to enhance the flame-like portion of this discharge, and to eliminate most of the "brush" part. A circular metal disk 16 inches (40 cm.) in diameter, provided with a 3-inch (7.5 cm.) hole at its center, and with ¼-inch (0.6 cm.) guard tubing facing all edges, was hung centrally over, and about 3 inches (7.5 cm.) above the 2-inch sphere (5 cm.) terminal by means of non-conducting supports. Figure 2 is a photograph of the steady flame-like discharge that occurred from the sphere to the plate. This photograph was naturally obtained by a legitimate artifice. In the laboratory, everything was dark when the first exposure was made and the flame photographed; and then by using some flash-light powder, all the apparatus was illuminated so that it could be photographed also. The flame, tho very strong, gives off no great amount of luminous radiation. The voltage and frequency were the same as before, viz., 50,000 and 88,000. The temperature of this flame was high. It melted quartz, rapidly disintegrated a tungsten lamp filament, and formed a bead on the end of a Nernst lamp filament. The metal of the electrodes was not greatly heated, and little or no metallic vapor appeared to enter the arc stream.

This flame discharge is not stable under all conditions. For example when the inductance and capacity of the disk were increased by placing in contact with it one end of an insulated 1-inch (2.5 cm.) copper tube 4 feet (1.2 meter) long, the flame discharge was no longer quiet and stable, but became noisy

porcelain near to or in contact with the sustained radio frequency electrode. In an actual case, the electrode was a ½-inch (1.2 cm.) aluminium tube laid in the top groove of a 33 kilovolt porcelain line insulator that was itself placed on an insulating support and mounted remote from all objects of opposite or ground potential. On the application of 35 kilovolts at 200,000 cycles, the air between the tube and insulator was overstressed, small flame discharges conducted the insulator charging currents to the porcelain surface where one or more brilliant hot spots would appear in about 30 seconds. Further study developed the fact that these hot spots were the heads of corresponding hot conducting cores that extended into the depth of the porcelain, thus establishing by conduction new routes for the delivery of the charging currents taken by the porcelain mass. No insulation that supports a conductor charged with high voltage at sustained high frequencies can endure, unless it is so designed that not a particle of air or other gas in contact with it is overstressed under actual working conditions. The Fortescue and Farnsworth principle can be employed in the design of such supporting insulators so as to suppress all overstress of air adjacent to the porcelain or other solid dielectric.[1]

## SUSTAINED RADIO FREQUENCY CORONA ABOUT A WIRE

The general arrangement of the equipment employed for the sustained radio frequency corona study is shown in the diagram of Figure 3; and a photograph thereof in Figure 4. The corona was formed around a number 19, B. & S. gauge clean copper wire* held axially in a galvanized iron cylinder, 15 inches (38.1 cm.) in diameter and 35 inches (88.9 cm.) long. Twelve (12) inches (30 cm.) of the wire at the center of the cylinder were normally left clear, and the remainder was shielded by two brass tubes 7-16 inch (1.1 cm.) in diameter. A third tube ½ inch (1.2 cm.) in diameter was arranged to slip over the central portion of the wire, and shield that too when desired. In this manner the corona could be suppressed, or it could be allowed to develop by removing the copper tube from the wire, and thus greatly increasing the stress on the atmosphere adjacent to the wire (because of the smallness of the wire circumference). We could thus check up the accuracy of the cathode ray power measuring meter.

[1] "*Air as an Insulator when in the Presence of Insulating Bodies of Higher Specific Inductive Capacity,*" C. L. Fortescue and S. W. Farnsworth, "Trans. Am. Inst. Elec. Eng'rs," 1913, Vol. XXXII, page 893.

* Diameter of wire = 0.036 inch = 0.092 cm.

Various voltages up to about 30 kilovolts, (root-mean-square), were impressed on the wire at sustained radio frequencies of 88,000 and 188,000 cycles per second; also at 60 cycles per second for comparisons. The appearance of the coronas at radio and audio frequencies differed greatly, while those at the

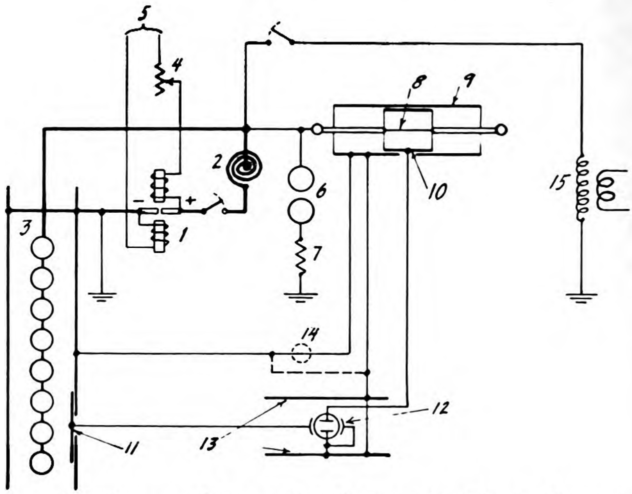


FIGURE 3—Diagram of Connections for Sustained Radio Frequency Corona Investigation

1—Arc Generator
2—Air Inductance
3—Air Condenser
4—Resistance
5—To 1200 Volt D. C. Supply
6—Sphere Gap Voltmeter
7—Carborundum Resistance
8—Corona Wire
9—Cylinder
10—Potential Tapping Cylinder
11—Potential Tapping Plate
12—Cyclograph Quadrants
13—Guard Plates
14—Carbon Lamp Resistance
15—60 Cycle High Voltage Transformer

two radio frequencies differed only slightly. That is to say, the enormous difference in corona at radio frequencies and at audio frequencies such as 60 cycles, is a difference that has come about perhaps gradually on the way up from 60 cycles to some such value as 50,000 cycles. At all events, to double, or a little more than double the frequencies when one is operating at a frequency of as high as 80,000 cycles, produces very little effect on the character of the phenomenon. The radio frequency corona appeared very active, it was quite brilliant and noisy and gave off an appreciable amount of heat. At 30 kilovolts the average diameter of the radio frequency corona was about 2 inches (5 cm.) whereas that at the audio frequency appeared to be less than 1-8 inch (0.3 cm.). A photograph of these coronas is reproduced in Figure 5. Two exposures were

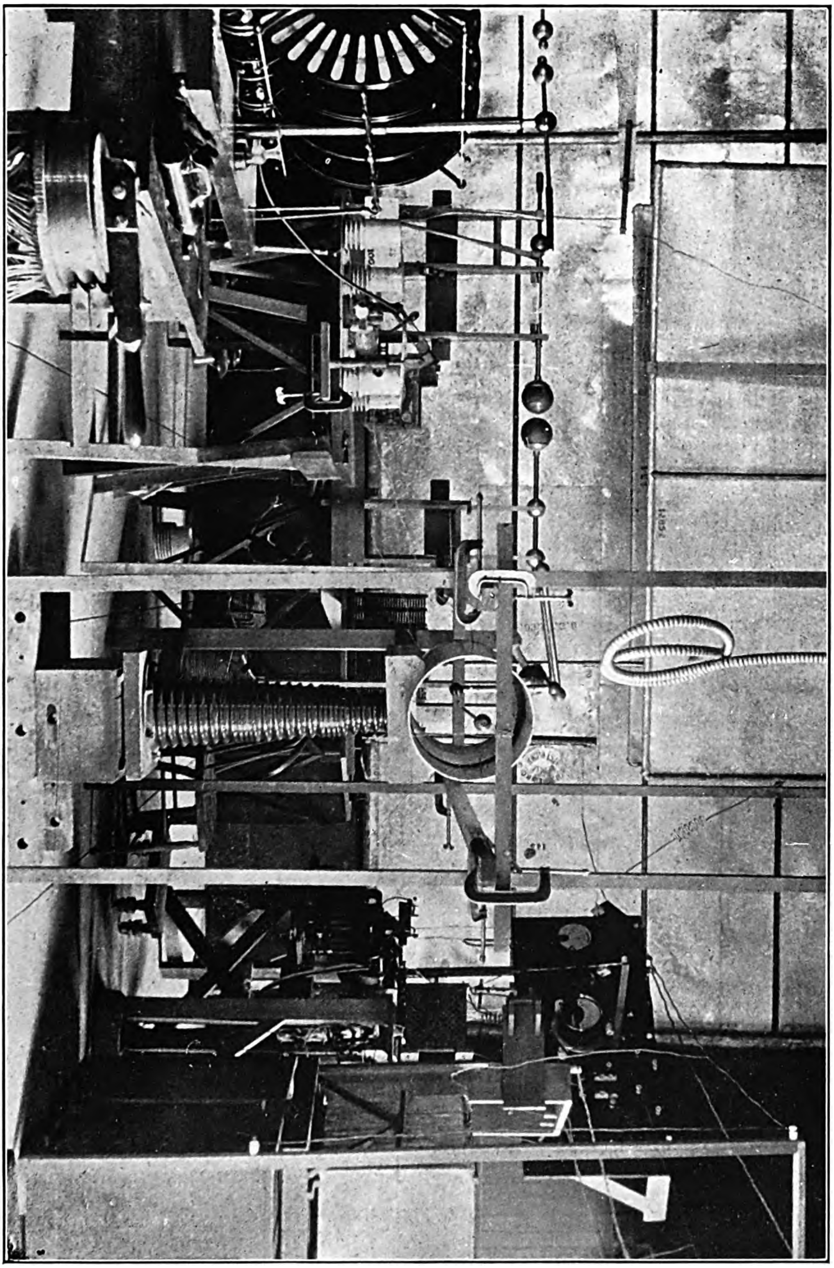

FIGURE 4

to the standardization of these gaps. Our work has indicated very closely that there is little difference between the indications that a sphere electrode gap will give for given values of voltage at radio and at audio frequencies. However, for the exact interpretation of the result as given here, the footnote will be helpful. The density of the atmosphere was that due to ordinary temperatures near sea level. Twelve and seven-tenths (12.7) kilovolts were required to start the corona at 188,000 cycles and 13.2 kilovolts correspondingly at 60 cycles. The indications of the sphere gap were here assumed to be independent of changes in frequency.

Cyclograms were taken of the energy consumed per cycle in the corona about the wire at 60, 88,000 and 188,000 cycles and at voltages ranging from 15,000 to 20,000 to determine the relative power factors and the wave forms of the currents flowing from the wire. The cathode ray tube was used in taking these cyclograms. The details of the method used have been given in the "Transactions of the American Institute of Electrical Engineers."[1] The actual arrangement of the cyclograph with its voltage and current condensers as used in the present work is given in the diagram of Figure 3. Various trials were made to determine that the cyclograph gave true indications within its limits of action when high frequency high voltage was used. These trials were as follows. When the wire at number 8, Figure 3, was screened from corona formation by sliding the ½-inch (1.2 cm.) brass tube over it, the cyclogram would close up into a right line loop without area. Thus arranged, by inserting an ordinary incandescent lamp at number 14 the cyclogram would open so as to enclose a large elliptical area. Again using the radio frequency high voltage, the effect in the results due to the hysteresis or other loss in the glass of the cathode ray tube was found to be negligible by noting that a no-area cyclogram obtained with all four quadrants mounted on the exterior wall of the tube remained as such when all conditions continued the same except that one pair of quadrants was mounted within the tube.

In Figure 6 sample cyclograms are reproduced. With the aid of the lantern, enlarged images of these cyclograms were thrown upon a sketching board and tracings carefully made. Figure 7 was engraved from these tracings. The distortion noted is due to the fact that the only suitable tube available

[1] "*A Power Diagram Indicator,*" Harris J. Ryan, "Trans. Am. Inst. Elec. Engin'rs," 1911, Vol. XXX, pages 1089–1113.

quency or audio frequency discharges, and in Figure 10 for combined audio and radio frequency discharges. A photograph of the electrodes and the sustained radio frequency discharge between them is reproduced in Figure 9.

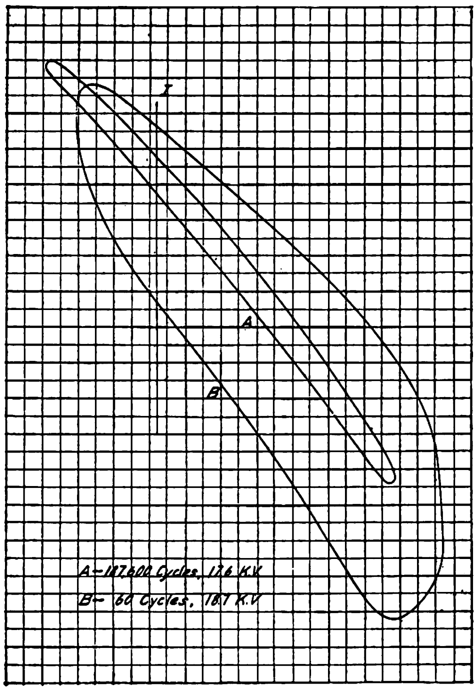


FIGURE 7

The blunt pointed electrode connected to the high frequency source was a square ended piece of number 12, B. & S. gauge copper wire,* projecting axially from the main radio frequency high voltage electrode, constituted as before of a 1-inch (2.5 cm.) copper tube ended with a 2-inch (5 cm.) copper sphere. A galvanized iron sheet, 3 feet (91.4 cm.) square, was used as the grounded electrode. Carborundum resistances (see number 5, Figure 8), were employed at strategic points to avoid short-circuiting the machines that supplied the arc generator with continuous current. The 5-inch (12.7 cm.) sphere gap at number 4, Figure 8, was used to measure all voltages. The sustained radio

* Diameter of number 12 wire = 0.081 inch = 0.21 cm.

electrodes. Facilities were lacking for the measurement of the large amounts of power that were evidently consumed in these brushes.

The 60-cycle voltage source was substituted for the arc generator in this sustained radio frequency point to plate discharge equipment diagrammed in Figure 8; and voltage discharge distance measurements were then made to compare with the corresponding sustained radio frequency discharge distance

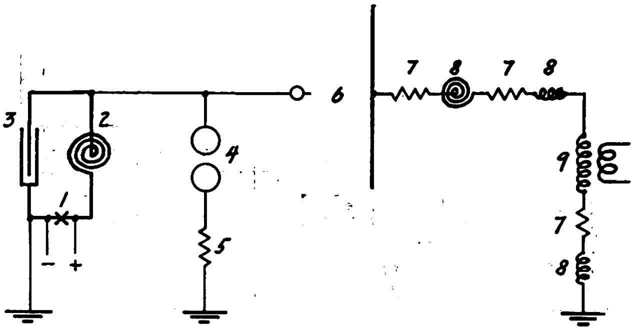


FIGURE 10—Diagram of Connections for Discharge with Combined Radio and Audio Frequency Voltage

1—Arc Generator
2—Air Inductance
3—Air Condenser
4—Sphere Gap Voltmeter
5—Carborundum Resistance
6—Point to Plate Gap
7—Carborundum Protective Resistance
8—Protective Air Inductance
9—60 Cycle High Voltage Transformer

measurements. Likewise for comparison a few determinations were made of the radio and audio cycle voltages required to discharge from the same blunt point to a similar blunt point in lieu of the galvanized iron plate.

The results obtained for the audio and radio frequency discharges are charted in Figure 11; and for the composite discharge values produced by the simultaneous application of sustained radio frequency voltage from earth to the blunt point and of 60-cycle voltage from earth to the plate are given in Table I. Two forms of discharge occurred and are designated "spark" and "arc" discharge. The former occurred at a somewhat lower voltage than the latter. The spark functioned to discharge the main condenser of the radio frequency generator and the arc to short circuit the 60-cycle and 1,200-volt direct current sources. The sums, equivalents and differences recorded also in Table I, and the values at corresponding differences charted in Figure 12 assist one to understand the parts that each voltage took in forming the composite discharges.

the distances thru which the individual voltages discharge. In Table I, column 2, the radio frequency voltages alone would have discharged the distances given in column 6[1], which when subtracted from the actual discharge distances in column 1, give the distances in column 7 as the added discharge distances due to the audio frequency voltages in column 4. These audio frequency voltages and the added discharge distances they caused are charted in Figure 12. For comparison the A. I. E. E. standard

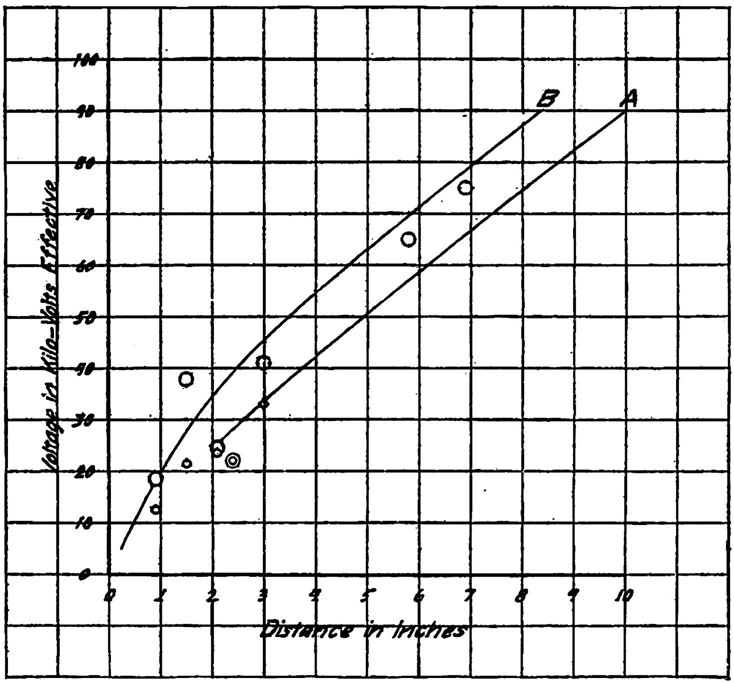


FIGURE 12—Plot to Accompany Table 1

For points marked thus—o Abscissas Represent Values in Column 7, Ordinates in Column 3
For points marked thus—O Abscissas Represent Values in Column 7, Ordinates in Column 4
A—Curve B of Figure 11
B—A. I. E. E. STANDARD Needle Gap Curve

needle gap voltage discharge curve and the 60-cycle point to plate discharge curve of Figure 11 are also charted as curves "B" and "A" in Figure 12. It is thus seen that the added dis-

[1] These distances were observed for the conditions shown in Figure 10, and are not identical with distances for corresponding voltages observed for the conditions in Figure 8 and charted in curve A, Figure 11.

charge distances due to the superimposed audio frequency voltage are practically the same as the corresponding discharge distances produced by the identical audio frequency voltages acting alone. In making this comparison, one must hold in mind the fact that the added discharge distance caused by the superposition of the 60-cycle voltage should naturally be somewhat greater than the discharge distance produced by such audio cycle voltage acting alone; because in the former case, no initial voltage is required to start corona at the blunt point; such corona is started by the sustained radio frequency voltage.

The authors desire to acknowledge herewith the valuable assistance rendered by their departmental co-worker Professor J. C. Clark.

SUMMARY: 1. Sustained radio frequency corona brushes or flames once started are maintained at much lower voltages than those required to start them by overstressing and ionizing the atmosphere. They quickly destroy even the most refractory insulations by their heating and ionizing properties.

2. The power factor of the charging current of a conductor in corona due to the application of sustained radio frequency high voltage is decidedly lower than the corresponding power factor at audio frequencies. Nevertheless, because of the high values of the currents that produce the radio frequency coronas, the losses they cause may be hundreds of times the corresponding audio frequency losses.

3. The sustained radio frequency voltage required to discharge between corona-forming electrodes may be as low as one-third of the corresponding audio frequency voltage. At higher voltages this ratio will probably be found to be less than one-third.

4. Sustained radio frequency and audio frequency voltages when combined, discharge thru distances between corona-forming electrodes that are substantially the sum of the distances thru which such voltages would discharge when acting alone, due account being taken of their mutual aid in starting the corona at one or both of the electrodes, as the case may be.

## TABLE I

Combined Radio Frequency and Audio Frequency Voltages; Point to Plate Discharge

| 1 Gap Distance in Inches | 2 Radio Frequency Voltage in Kilovolts | 3 Audio Frequency Voltage for Spark Discharge | 4 Audio Frequency Voltage for Arc Discharge | 5 Sum of the R. F. and A. F. Voltages | 6 Discharge Gap Equivalent to Radio Frequency Voltage | 7 Difference, Column 6 Subtracted from Column 1 |
|---|---|---|---|---|---|---|
| 5 | 28.7 | .... | .... | .... | .... | ... |
| 5 | .... | .... | 51 | .... | .... | ... |
| 5 | 21.2 | 22 | .... | 43 | 2.6 | 2.4 |
| 5 | 21.2 | .... | 22 | 43 | 2.6 | 2.4 |
| 5 | 22.4 | 23.5 | .... | 46 | 2.9 | 2.1 |
| 5 | 22.4 | .... | 24.5 | 47 | 2.9 | 2.1 |
| 5 | 26.4 | 12.5 | .... | 37 | 4.1 | .9 |
| 5 | 26.4 | .... | 18.5 | 45 | 4.1 | .9 |
| 12 | 42.9 | .... | .... | .... | .... | ... |
| 12 | .... | .... | 105 | .... | .... | ... |
| 12 | 29 | .... | 75 | 104 | 5.1 | 6.9 |
| 12 | 31.8 | .... | 65 | 97 | 6.2 | 5.8 |
| 12 | 37.5 | 33 | .... | 70.5 | 9.0 | 3.0 |
| 12 | 37.5 | .... | 41 | 78.5 | 9.0 | 3.0 |
| 12 | 40.3 | 21.5 | .... | 62 | 10.5 | 1.5 |
| 12 | 40.3 | .... | 38 | 73 | 10.5 | 1.5 |

Radio Frequency Voltages at 88,000 cycles. All voltages in terms of five inch (12.7 cm.) gap; the calibration being taken as Kilovolts (effective) $= 2 + 45.5 \times$ (Gap Distance in inches) $= 2 + 17.9 \times$ (Gap Distance in cm.).

## DISCUSSION

**Robert B. Woolverton (Chairman):** On behalf of The Institute of Radio Engineers, I wish to acknowledge the great courtesy of the American Institute of Electrical Engineers in the arrangements it has made for this joint session.

As the advantages of the use of long wave lengths in radio communication become more and more evident, it has become apparent to radio engineers that they are limited quite strikingly in the use of these long waves at high power by the formation of corona on the antenna. It is obvious, therefore, that any light that can be thrown on the subject of corona is of intense value to radio engineers.

**Robert H. Marriott:** As Mr. Woolverton has pointed out, a paper of this kind should enable us to anticipate what may be expected in the way of corona on high power station antennas, and in that way we can keep down costs. It will be remembered that the matter of antenna insulation has always been one of the important things in radio work.

**Haraden Pratt:** Does the resistance used in connection with direct current arc generator circuits vary with frequency? Another matter which arises in connection with this paper deals with harmonics produced in the working circuits. Taking a circuit of 100,000 cycles, I have been able to observe as many as 62 harmonics, some more or less strong than others. In the event that some parts of the apparatus subjected to the high potentials, such as the concentric brass tubes mentioned in this paper, should have a capacity that would reinforce one or more of these harmonics, might not the added steepness of the very high frequency wave affect the character of the corona ?

**Harris J. Ryan:** I have had no experience with the variation in the resistance of the carborundum rods with frequency. I understand that their resistance does vary with frequency. We were compelled to use these rods as a matter of strategy in preventing short circuit currents. Otherwise, it would have been disastrous for our apparatus. The values of the resistance, however, were so low that the results were not affected by the presence of these rods. We are confident of that. We made tests and assured ourselves of the fact that we were not using too much resistance.

Unavoidably harmonics are produced in the driving voltage of the Poulsen arc generator. However, in generating high

voltage, the inductance of the oscillating circuit must be made relatively large and the capacitance relatively small. The harmonics in the arc voltage do not, as a consequence, drive corresponding currents in appreciable amounts thru the whole of such inductance. These currents penetrate only a few of the outer turns of the inductance whence they are shunted by the local capacitance of such turns; thus it comes about that the harmonic voltages are not impressed thru the entire inductance and do not reach the main electrode in appreciable amounts. This we have demonstrated conclusively by means of the cathode ray voltage oscillograph.

**Ellery W. Stone:** In the paper (on page 353), it is stated that "Further study developed the fact that these hot spots were the heads of corresponding hot conducting cores that extended into the depth of the porcelain." I should be interested in having Professor Ryan explain how the hot conducting cores in the porcelain were detected.

**Harris J. Ryan:** We have within the last two years again and again applied these sustained radio frequency high voltage discharges to porcelain insulators of many different patterns and sorts. We know that a molten conducting core is formed, because when a high voltage of radio frequency is applied in the manner indicated in the paper in the immediate neighborhood of the insulator, there is at first quite a corona display for a few moments due to the breakdown of the air near the electrode. This disappears immediately when a bright hot spot forms under or near the electrode, and this bright spot is of a yellowish white incandescence. As soon as such bright spot appears the charging current need no longer be furnished thru the outside conducting air (corona); but, since there is a conductor thru the porcelain, the charging current passes to it laterally thru the porcelain.

As regards the molten condition of this core, the discharge can be driven to the point that there is actual plasticity. In fact, if an opposing electrode is placed under the porcelain, so that directive forces are present, the conducting core is driven thru the porcelain from one electrode to the other. This experiment has been performed with porcelain one-half inch (1.27 cm.) thick, but there is no reason why it should not be performed with thicker porcelain. In these experiments, the hot spot has appeared at each side, and the corona has simultaneously disappeared. Upon stopping the application of the high voltage,

the core promptly cools and solidifies. If the porcelain is broken apart thru the core it is found to be smooth grained, brittle and glass-like. Left mechanically undisturbed it is often, tho not always, found to have regained most of its original dielectric strength; i.e., it will endure the application of audio frequency voltage to the flash-over point. Renewed application of the radio frequency high voltage without change in the position of the electrodes will generally, tho not always, re-establish the hot conducting core in the former position.

An interesting variation in this experiment may be made to demonstrate the powerful mechanical drive that exists in the path of an electric spark. When a hot core thru the porcelain has been produced the main electrode is drawn away from the porcelain, say 3 to 5 inches (7.5 to 12.5 centimeters). This will stop the current flowing conductively thru the porcelain hot core and reactively thru the rest of the porcelain. Simultaneously the radio frequency voltage is raised to the value whereat the air between the main electrode and the hot core in the porcelain is ruptured. A spark is thus set up. It discharges the main condenser of the radio (high) frequency source thru the hot, plastic core in the porcelain. This spark stops the generation of the radio frequency high voltage. By the recovery of the generating action of the source in an obvious manner, such voltage is quickly renewed so that several sparks per second follow one another. When a few sparks have passed, the high voltage is turned off and the specimen is allowed to cool. It is then broken open whereupon one will often find that a clear hole of small calibre, diameter one-fiftieth of an inch (one-half millimeter), or thereabouts, has been made thru the porcelain core by the blast of the spark. There is here some evidence of the electro-physical manner in which a real open puncture is formed thru a refractory dielectric.

In a paper presented to the American Institute of Electrical Engineers before another section here to-day, Mr. F. W. Peek, Jr., demonstrates that it requires a much shorter time to build up and to produce under high voltage a discharge between spherical electrodes than between pointed, sharp or even blunt electrodes, as long as the "sharp" electrodes are not so blunt as to prevent corona from being formed in advance of the discharge. This is in contradistinction to an arrangement where spherical electrodes are employed and they are not widely separated, so that the corona is not formed in advance of the discharge. This is a matter of great practical importance in deal-

ing with the question of arranging properly static arresters and reliefs. Incidentally, evidence related hereto was produced by the following experiment at sustained radio frequency high voltages. Near the main helix of the arc generator, a companion helix was mounted. Connected in series therewith was a high voltage adjustable condenser, so that one might easily, by turning the handle of that condenser, pass thru such a capacity value as to bring about resonance in the circuit thus formed. The detached helix was four or five feet away from the arc helix and the oscillating circuit of the generator, and was connected to nothing save the adjustable condenser. In order to ascertain when the circuit was in tune for the frequency of oscillation of the generator, there was connected across the terminals of the condenser a needle gap set at about an inch (2.5 cm.) length. As one passed thru the exact value for the capacity required to produce completely effective tuning, an arc would be set up between the needle points. They were promptly melted, because of the rather large amount of power present. Then it was noticed that unless one passed thru the correct capacity value slowly, the discharge did not have time to build up between the needle points. It was necessary to pass thru the resonance value very deliberately. To build up the discharge between the points required appreciable time because it required the absorption of considerable energy. Prolific ionization had to be produced to bring about the discharge.

**Roy E. Thompson:** Another explanation occurs to me, however. If two such circuits are coupled, in general (for electrical reasons) the second circuit will not follow the first one rapidly enough to admit of Morse signals in the first circuit being clearly indicated in the second. The "building up" of current takes too long in the second circuit, and detuning may occur thru reaction on the first circuit. Might this not be the explanation here also?

**Harris J. Ryan:** The point is well taken. If there is any effect in connection with these coupled circuits which throws one out of tune as the other is tuned to resonance when the action is performed rapidly but not when it is performed slowly, then this would be an explanation of the time required for the discharge to culminate. This is a matter which must be studied with great care to prevent arrival at erroneous conclusions.

**Roy R. Thompson:** If there were a means for controlling

the energy of the primary circuit, it would be possible to note whether the discharge took place immediately after closing the primary circuit. The retardation due to variation of the secondary condenser could then be separately studied.

# THE EFFECTIVENESS OF THE GROUND ANTENNA IN LONG DISTANCE RECEPTION*

By

R. B. Woolverton

The subject of this paper was suggested in October, 1914, when resonance curves were being taken by the writer at Eccles, Cal., on waves emitted by the various high powered commercial stations situated in the vicinity of San Francisco, at a distance of approximately 100 miles. The antenna used in taking these resonance curves consisted of the top wire of a 5-foot (1.6 meter) fence extending in a northwesterly direction for a distance of approximately 4,000 feet (1,300 meters). Altho the antenna so used was quite aperiodic, as might be expected, the received energy in the secondary circuit was remarkably large, signals being heard from stations in the Hawaiian Islands and Alaska. By using the ordinary crystal detector, full scale deflection was obtained on a Leeds & Northrup portable galvanometer when taking resonance curve data on the wave emitted by the high powered Marconi station at Bolinas, Cal.

In view of the results obtained at Eccles, the writer conducted on October 9th and 10th, 1915, experiments of a somewhat more quantitative character at the Palmer B. Hewlett ranch, situated 90 miles (140 kilometers) south by east of San Francisco. The receiving apparatus was of the de Forest "ultraudion" type (oscillating audion), using a second step amplifier audion bulb, and the audibilities were read on a "Wireless Specialty" audibility meter.† The connections are shown in detail in Figure 1.

It will be noted that two pairs of telephone receivers are connected in series, thus reducing the audibilities nearly 50 per cent., but it was found that the audion circuit would not oscillate when but one pair of receivers was used, with the audibility meter shunted about it.

Before beginning the experiments, it was thought that a com-

*Presented before The Institute of Radio Engineers, New York, November 3, 1915.

(†A variable multi-contact resistance, graduated directly in "times audibility" for use with a definite telephone receiver of the Pickard type.—Editor.)

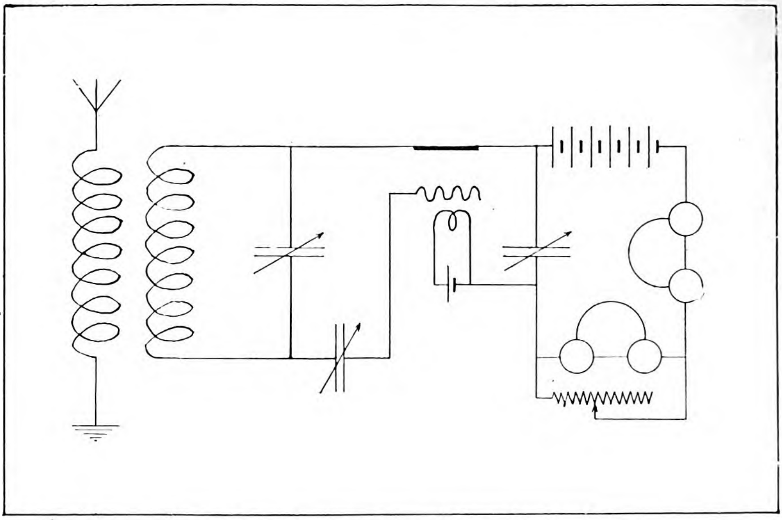

FIGURE 1—Diagram of Connections

paratively long single wire antenna would be so directional in effect that it was decided to confine the readings to one particular station; and Sayville, Long Island, was chosen, the antenna being made as nearly directional toward that station as possible. Buildings slightly interfered with this plan, however, and the antenna's true direction from the receiving apparatus was west-southwest, instead of more nearly west. As soon as readings were begun, it became apparent that this directional effect did not exist, as will readily be seen from the Honolulu audibilities in the "Audibility Table," Figure 2, and the "Direction and Range Chart," Figure 3. The two antennas consisted of 500-foot (160 meters) and 1,000-foot (320 meters) lengths respectively of a single Number 28 B. & S., cotton covered, magnet wire,* laid on dry earth without support at any point. The audibilities for the four transmitting stations are shown in Figure 2.

It will be noted that in the case of each station received from, the signal strength is more than sufficient for reliable communication, particularly when it is realized that the audibility of atmospherics was unity in each case. Atmospheric audibilities taken during the period of the tests, on a five-wire antenna, 45 feet high and 300 feet long, averaged 100.

Figure 3 shows the direction of the antenna with respect

* Diameter of Number 28 wire = 0.0126 inch = 0.0320 centimeter.

| ANTENNA | SAYVILLE | HONOLULU | ARLINGTON-ARC | ARLINGTON-SPARK |
|---|---|---|---|---|
| 500 FEET | 50 | 100 | 60 | 100 |
| 1000 FEET | 80 | 160 | 80 | 160 |

FIGURE 2—Table of Audibilities

to the stations received from, with the distances of the stations plotted to scale; and it immediately suggests experiments to determine the most effective design of a ground antenna. These experiments will shortly be undertaken by the writer, using various lengths, heights from the earth, and high potential ends both open and earthed. In view of the comparatively high ohmic resistance of the antenna wire used in the above tests,

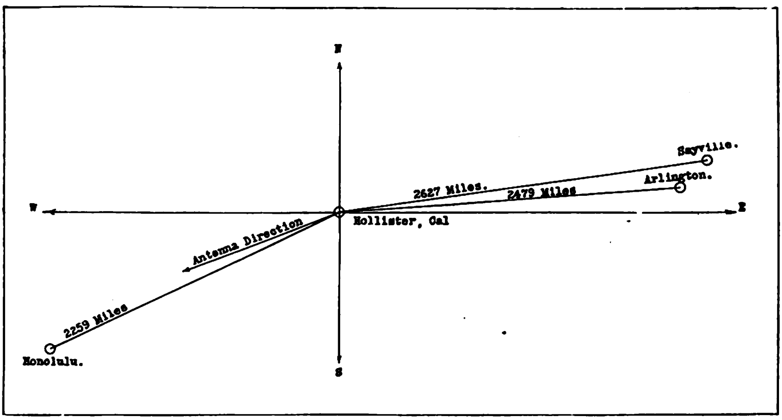


FIGURE 3—Direction and Range Chart

the use of a larger wire should give considerably greater audibilities. If such should be the case, and sufficiently high audibilities are obtained for daylight reception, it would seem that the ground antenna may be the solution of the serious problem of eliminating atmospheric interference, not to mention the difference in cost of the construction and maintenance of such an antenna, as compared with that of the present type.

In closing the writer wishes to express his appreciation for the courtesy and valuable assistance rendered by Mr. Palmer B. Hewlett, of Hollister, Cal.

**SUMMARY:** Using an antenna several hundred meters long stretched on the ground, signals of an audibility up to more than one hundred are received from sustained wave stations 4,000 kilometers away. Atmospheric disturbances are found by the experimenter to be less troublesome relatively than when using a normal antenna. A further series of development experiments are outlined and will be undertaken.

## DISCUSSION

**Alfred N. Goldsmith:** In presenting this paper to the New York membership of the Institute, it is to be noted that the paper gives only preliminary experiments and that Mr. Woolverton is carrying on further experiments and will lay the results of these experiments before the Institute. The paper is merely an introduction. It is further to be noted that Mr. Woolverton is well aware of the previous work done in this field by Messrs. Marconi, Braun, Zenneck, Kiebitz, Taylor and others.

**Lester L. Israel:** So far as the ground antenna is concerned, it has been worked with very largely without much success in the past. In Cuba particularly, a ground wire 1000 feet (300 meters) long was used and signals were received with about the same intensity as on an antenna 100 feet (30 meters) high. So far as atmospheric disturbances were concerned, the results were anything but satisfactory. It must be mentioned that if any advantages were obtained by Mr. Woolverton in the use of the ground antenna, the ground conditions in the neighborhood where the experiments were tried would be largely responsible.

**Alfred N. Goldsmith:** In reading thru a number of papers on this topic by Kiebitz, it was found that this experimenter claimed that he found no change in the ratio of signals to atmospheric disturbances of reception by using the ground antenna, as compared with the ratio for an ordinary antenna.

**Lester L. Israel:** In experimenting with ground antenna, Mr. Hill found that an antenna grounded at one end could be tuned but in cases where it was entirely ungrounded, tuning was practically impossible.

**Roy A. Weagant:** From the statements which have been made so far, it is not very clear whether Mr. Woolverton was working in the immediate vicinity of the elevated aerial or not. I believe that Mr. Woolverton referred to an aerial about 45 feet (15 meters) high. The influence of such an aerial on reception by means of a wire stretched on the ground would be very great.

We are not able to judge completely as to the efficacy of the ground antenna in eliminating atmospheric disturbances, because Mr. Woolverton gives the strength of atmospheric disturbances and signals on his ground antenna and the strength

of atmospheric disturbances on the elevated antenna, but he does not give the necessary data as to the strength of signals of the elevated antenna. Such information should be sent.

So far as my own experiments are concerned, I do not know if there is any advantage in using the ground antenna. It seems that the ratio between signal strength and disturbance strength is constant regardless of the type of antenna used. Sometimes advantages which are obtained with low aerials are due to the fact that the receiver used, for example the audion, has an upper limit of response. If it is struck by a stray impulse of more than a certain strength, it is simply temporarily paralyzed, and no further immediate response is obtained.

**Alfred N. Goldsmith:** In connection with the experiments which Mr. Woolverton is carrying out, any suggestions addressed to Mr. R. B. Woolverton, Custom House, San Francisco, Cal., will be welcomed by Mr. Woolverton, who is interested in obtaining the widest possible expressions of opinion relative to experiments of this type.

**Robert B. Woolverton:** Every effort was made to prevent the elevated antenna from affecting the results on the ground antenna. The elevated antenna circuit was kept wide open, and in addition its direction was exactly at right angles to the ground antenna. However, in future experiments, the elevated antenna will be taken down.

Every effort was made to keep the sensitiveness of the ultraudion constant. The Los Angeles station of the Federal Telegraph Company provided signals used as a reference constant before reading audibilities on other stations. Furthermore, the de Forest bulb used in all the tests was an especially good one, and practically no difficulty was experienced in keeping its sensitiveness constant.

# THE DESIGN OF THE AUDIO FREQUENCY CIRCUIT OF QUENCHED SPARK TRANSMITTERS

By

Julius Weinberger

(Including a Supplementary Discussion of "Resonance Phenomena in the Low Frequency Circuit," by H. E. Hallborg, Proceedings of the Institute of Radio Engineers, Volume 3, Part 2, 1915, page 107.)

A large number of contributions to the literature of radiotelegraphy have been made upon the subject of the so-called "resonance transformer." These have been both experimental and theoretical. The experimental contributions, as a general rule, have been investigations of the resonance transformer under actual operating conditions (that is, with the secondary condenser discharging periodically thru a spark gap), while the theoretical contributions have generally assumed a steady state of affairs (the secondary condenser *not* being discharged); in this case the method of treatment has been that employed for two coupled circuits.

In actual practice, such as in the operation of quenched gap sets, the requirement of a clear note involves the discharge of the secondary condenser at the peak of the wave each half cycle. It would seem, therefore, that the *transient* phenomena in the circuit would be the determining factors of voltage and current, rather than those of the steady state of affairs; that is, conditions would never assume the steady state.

To investigate these conditions, we can reduce the whole resonance transformer circuit to that of a simple inductance, capacity and resistance in series (Figure 1), as has been shown by Mr. Hallborg. The inductance **L** includes all the inductances in the circuit—generator inductance, transformer leakage inductance, inductance of any series choke coils, and so on. The condenser **C** is the secondary condenser reduced to the primary circuit by multiplication by the square of the ratio of transformer voltages. The resistance **R** includes resistances in the primary circuit and resistances in the secondary circuit reduced to the primary by division by the square of the ratio of transformer voltages.

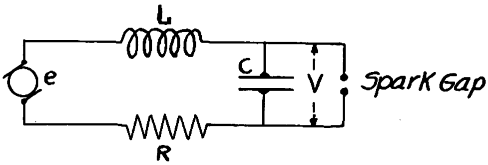


FIGURE 1

The differential equation for such a circuit is

$$e = E \cos (\theta - \theta_o) = R i + x \frac{d i}{d \theta} + x_c \int i \, d \theta$$

where

$E$ = maximum generated * voltage
$x_c$ = condenser reactance
$x$ = inductive "
$\theta = \omega t$
$\theta_o$ = an angle to be subtracted from $\theta$ if e is not zero for $t = 0$.

The potential difference across the condenser terminals can be found from

$$V = x_c \int i \, d \theta$$

when equation (1) has been solved for **i**.

Since we are mainly concerned with this **V**, we will omit writing the solution for i, but give that for **V** immediately:

$$V = \frac{E x_c}{Z} \sin (\theta - \theta_o - \gamma) + \frac{E x_c}{Z} \varepsilon^{-\frac{R}{2x}\theta} \left\{ \sin (\theta_o + \gamma) \cos \frac{q}{2x} \theta \right.$$
$$\left. + \left[ \frac{R}{q} \sin (\theta_o + \gamma) - \frac{2x}{q} \cos (\theta_o + \gamma) \right] \sin \frac{q}{2x} \theta \right\}$$
$$+ \varepsilon^{-\frac{R}{2x}\theta} \left\{ e_o \cos \frac{q}{2x} \theta + \frac{2 R e_o + 4 x x_c i_o}{2 q} \sin \frac{q}{2x} \theta \right\}$$

where

$Z$ = impedance,
$\gamma$ = phase difference between generated e. m. f and i
$q = \sqrt{4 x x_c - R^2}$

$e_o$ = value of potential difference across condenser terminals at the time $t = 0$

$i_o$ = value of current thru the circuit at the time $t = 0$.

*This is *not* the voltage across the generator terminals. If the generator armature has appreciable inductance (in comparison with the rest of the circuit) there will be a drop in voltage inside of the armature and a very much higher voltage will actually be *generated* than that which is measured at the terminals.

Consider the conditions introduced in the circuit immediately after the condenser has sparked over, at one peak of a cycle, and the spark has ceased. This is the moment for which we take $t = 0$. The important thing to be determined is:—what will be the voltage across the condenser for $\theta = \pi$ (that is, at the next peak of the cycle)? Will it rise to a sufficient value to cause another discharge? Or, rather, will it rise to a value equal to that, at least, at which the previous discharge took place? If not, the requirements of a clear note, of twice the generator frequency, will not be fulfilled. Also, it is this discharge voltage which determines the energy absorbed by the condenser.

Taking the equation given for V, we can introduce the following simplifications:

(1) Since we will consider the circuit as being resonant, we have $x_c = x$, and shall substitute x for $x_c$ accordingly, thruout.

(2) Since the circuit is resonant, the current and generated voltage are in phase, hence $\gamma = 0$.

(3) When the condenser discharges, the potential difference between its plates is reduced to zero. Hence. at the moment we are considering, $e_o = 0$

(4) The spark occurs when the generated voltage is zero. Since $i_o$ is in phase with $e_o$, $i_o = 0$.

(5) Since the circuit is resonant, $Z = R$.

(6) $R^2$ can usually be neglected as compared with $4\,x\,x_c$.

Hence $$q = 2\sqrt{x\,x_c}$$

Or, since $$x = x_c$$
$$q = 2x$$

(7) In our case, $$\theta_o = \frac{\pi}{2}$$

Substituting these conditions, we obtain

$$V = \frac{E\,x}{R}\sin\left(\theta - \frac{\pi}{2}\right) + \frac{E\,x}{R}\varepsilon^{-\frac{R}{2x}\theta}\left\{\cos\theta + \frac{R}{2x}\sin\theta\right\}$$
$$= \frac{E\,x}{R}(-\cos\theta) + \frac{E\,x}{R}\varepsilon^{-\frac{R}{2x}\theta}\left\{\cos\theta + \frac{R}{2x}\sin\theta\right\}$$

To show the general shape of this curve, which gives the voltage across the condenser at any moment after the time $t = 0$, it has been calculated for a specific case ($C = 20$ microfarads and $R = 1$ ohm), and is shown in Figure 2. In the same figure the curve of generated voltage (a sine wave), is given for comparison.

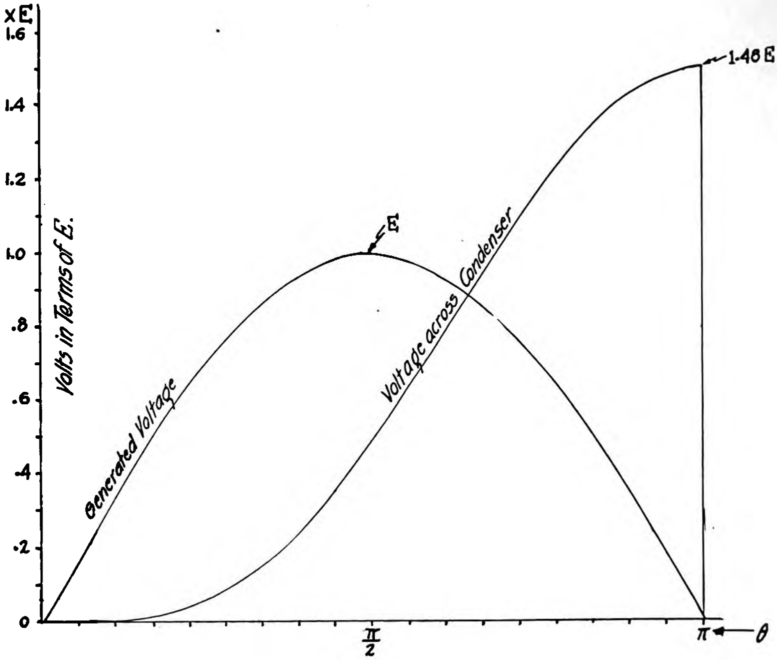


FIGURE 2

This condenser voltage, **V**, will reach its maximum for $\theta = \pi$. It will then be

$$V_{max} = \frac{E\,x}{R} - \frac{E\,x}{R}\varepsilon^{-\frac{\pi R}{2x}}$$
$$= \frac{E\,x}{R}\left(1 - \varepsilon^{-\frac{\pi R}{2x}}\right)$$

This, then, is the potential at which our "reduced" condenser will discharge. The actual condenser, across the transformer secondary, will, of course, discharge at a voltage which is simply this $V_{max}$ multiplied by the transformer ratio. In Figure 3, curves are given for $V_{max}$ in terms of **E** (the maximum generated voltage). It will be seen that for ordinary conditions of resistance (that is, **R** between zero and 1 ohm), V = 1.5 E is a good average value.

To find the R. M. S., or effective value of **V** is desirable, since this is the voltage that a voltmeter placed across the transformer primary will read, and this is also the voltage for which the transformer primary must be designed when the equation $V_{eff} = 4.44\,A\,B\,n\,f \cdot 10^{-8}$

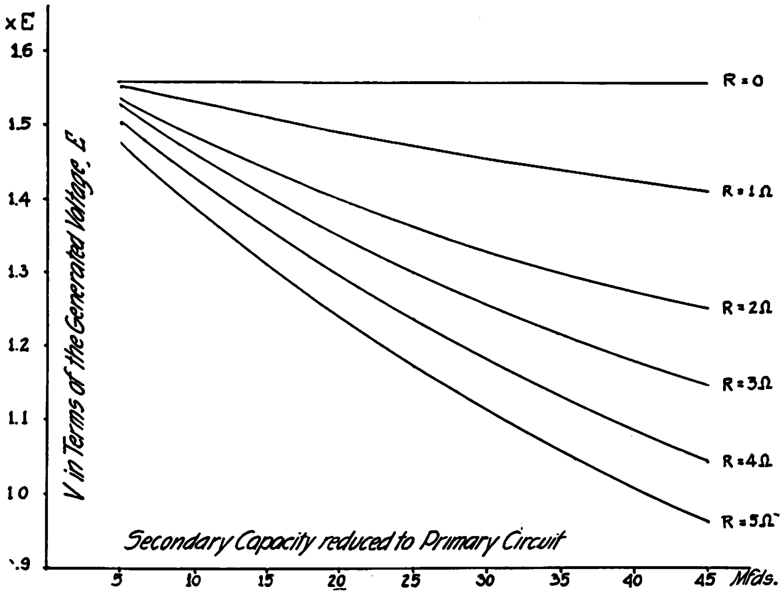


FIGURE 3

is used, where

$V_{eff}$ = R. M. S. volts across transformer primary
A = cross sectional area of core in square cms.
B = flux density, in lines per square cm.
N = number of turns of primary winding.
f = supply frequency.

This effective value of V is

$$V_{eff} = \sqrt{\frac{1}{\pi}\int_0^\pi \left(-\frac{E x}{R}\cos\theta + \frac{E x}{R}\varepsilon^{-\frac{R}{2x}\theta}\left\{\cos\theta + \frac{R}{2x}\sin\theta\right\}\right)^2}$$

It is found* that

$$V_{eff} = 0.504\ V_{max}.$$

The design of a quenched gap set to operate under resonance conditions becomes a relatively simple matter. Let us take a numerical example for a 500-cycle, 1 kilowatt set, operating with a 110-volt generator (154 volts maximum).

We shall first find the equivalent primary condenser (i. e. the secondary condenser reduced to the primary circuit), required to absorb 1,000 watts, from

$$W = n C V^2$$

*This value was determined graphically, the integration being done by measuring the area of the squared curve with a planimeter.

Since $\qquad V = 1.5\,E = (1.5)\,(110)\sqrt{2} = 233$ volts.

Hence $$1000 = 500\,C\,(233)^2,$$
$$C = 37 \text{ microfarads.}$$

To tune to 500 cycles with this capacity, an inductance of 2.5 millihenrys is required. This can be made up partly from the generator armature inductance (usually this is between 1 and 5 millihenrys for a 1 kilowatt, 110-volt machine), and the rest obtained either by a transformer having this amount of leakage inductance, or else from a transformer with no appreciable leakage and series choke coils. I believe the latter method to be preferable as it admits of greater flexibility.

The value of the equivalent primary condenser (or rather, the "reduced" secondary condenser, as I have called it), being now fixed, the actual secondary condenser is determined by deciding on a suitable transformer ratio. The value of this secondary condenser is usually limited by conditions of wave length and also by the discharge current which the quenched gap in use will stand. A large condenser means heavy currents and considerable heating in the gap, while a high discharge voltage and a small condenser would require many gap sections and cause insulation difficulties. It is, I believe, common practice to employ about 0.006 microfarads as a secondary condenser for this type of set.

Having thus determined the ratio of primary to secondary capacities, the transformer ratio is of course fixed; and it is only necessary to design a transformer of the ratio desired—a simple matter with a closed core transformer of negligible leakage. Note should be taken of the fact previously mentioned that when the usual transformer formulas are used, the effective value of V (that is $0.504\ V_{max}$) should be used as the voltage across the primary.

Practically, the operation of quenched gap sets is at a point slightly "off" resonance. However, it is hardly necessary to operate with a condenser as much as 20 per cent larger than the resonance capacity. The foregoing results can, therefore, be applied as very good approximations to actual practice; and have been found to be quite satisfactory for this purpose.

[Since the above was written I have become aware of an article by L. B. Turner* upon the same subject. Following a somewhat different procedure, Turner reaches practically the

*L. B. Turner: "Electrician," Vol. 69, 1912, page 694; "Der Schwingungskreis niedriger Frequenz in der Funkentelegraphie," "Jahrb. d. Drahtl Tel.," Volume 9, Heft 2, page 141.

same results as given above, with the exception that he neglects the resistance of the circuit. As Figure 3 shows, however, this would lead to considerable inaccuracies, for large resistances, and is strictly correct only for $R = 0$. Turner obtains the result

$$V = \frac{\pi}{2} E.]$$

WASHINGTON, D. C., July 1, 1915.

**SUMMARY:** The paper gives the operating theory of the power transformer and alternator circuit of quenched spark gap transmitters. The secondary of the transformer and its loading capacity are reduced in the usual way to equivalent primary inductance and capacity. The theory of the transient phenomena occurring at the sudden discharge of the condenser is then developed. It is shown that under ordinary conditions the maximum condenser voltage (reduced to the primary circuit), is 1.5 times the maximum voltage generated in the alternator. The effective (or R. M. S.) condenser voltage, reduced to the primary, is found to be 0.504 times the maximum primary voltage. It is this R. M. S. voltage which is used in the usual transformer design. The theory is clearly illustrated for the case of a 500 cycle 1 K. W. set.

# THE PUPIN THEORY OF ASYMMETRICAL ROTORS IN UNIDIRECTIONAL FIELDS

## WITH SPECIAL REFERENCE TO THE GOLDSCHMIDT ALTERNATOR.*

By

Benjamin Liebowitz

Since its advent, the radio-frequency generator of Professor Rudolph Goldschmidt has been the subject of much discussion, and several theories of its action have been advanced. The theory of the Goldschmidt alternator, however, is but a special case of the general theory of asymmetrical rotors in unidirectional magnetic fields, which latter has been developed by Professor Pupin, and on which he has been lecturing during the past seven or eight years. The Pupin theory, therefore, antedates the Goldschmidt alternator by several years, but is little known except to those who have attended his lectures. The object of this paper is to give the theory its due publicity.

### CIRCUIT HAVING VARIABLE INDUCTANCE AND NO RESISTANCE

It will be helpful, perhaps, before considering Pupin's problem, to take up a simple, hypothetical case first, viz., a circuit having a periodically varied self-induction and no resistance. Imagine a circuit made up of two coils connected in series, the one having inductance $L_1$, the other inductance $L_2$, and let M be the maximum value of the mutual inductance between the coils. When they make an angle $\theta$ with each other, the mutual inductance between the coils is $M \cos \theta$. (See Figure 1.) Let the circuit be supplied with a source of constant e. m. f., E (e. g., a battery), and let R be the resistance. If one of the coils is continuously rotated with angular velocity $\omega$, the total self-induction of the circuit will vary periodically in accordance with the equation

$$L = L_1 + L_2 + 2 M \cos \omega t.$$

* Delivered before the Institute of Radio Engineers, New York, May 5, 1915.

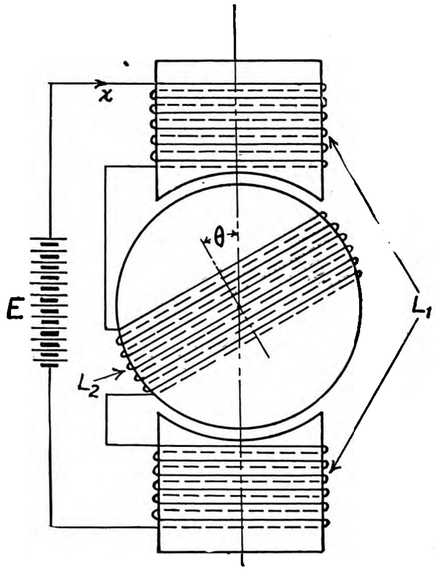


FIGURE 1

The inductance reaction will therefore be

$$\frac{d}{dt}\Big[(L_1 + L_2 + 2M\cos\omega t)\,x\Big],$$

where x is the current in the circuit at any instant. For brevity, put

$$L_1 + L_2 = \lambda,\ \ 2M = \mu,$$

and the inductance reaction becomes $\frac{d}{dt}\Big[(\lambda + \mu\cos\omega t)\,x\Big]$.

The resistance reaction is Rx, hence the equation of reactions is:

$$\frac{d}{dt}\Big[(\lambda + \mu\cos\omega t)\,x\Big] + Rx = E.$$

This equation, as it stands, comes under Pupin's problem; what we are interested in for the moment is the simplification which results when the resistance R is assumed to be vanishingly small. We must assume, of course, that E also becomes vanishingly small, altho the ratio $E/R = X$ is to be regarded as finite. With these assumptions the equation of reactions becomes

$$\frac{d}{dt}\Big[(\lambda + \mu\cos\omega t)\,x\Big] = 0,$$

the solution of which is

$$(\lambda + \mu\cos\omega t)\,x = K,$$

whence $$x = \frac{K}{\lambda + \mu \cos \omega t}.$$

K is a constant of integration, depending on the initial conditions. If we assume, for example, that

$$x = X \text{ when } t = 0,$$

then $$K = (\lambda + \mu) X = (\lambda + \mu) \frac{E}{R}.$$

Therefore $$x = \frac{(\lambda + \mu) X}{\lambda + \mu \cos \omega t}.$$

This equation shows how the current varies in a circuit having a periodically varied self-induction, an initial current, and no resistance. Its graph is given in Figure 2 for the case

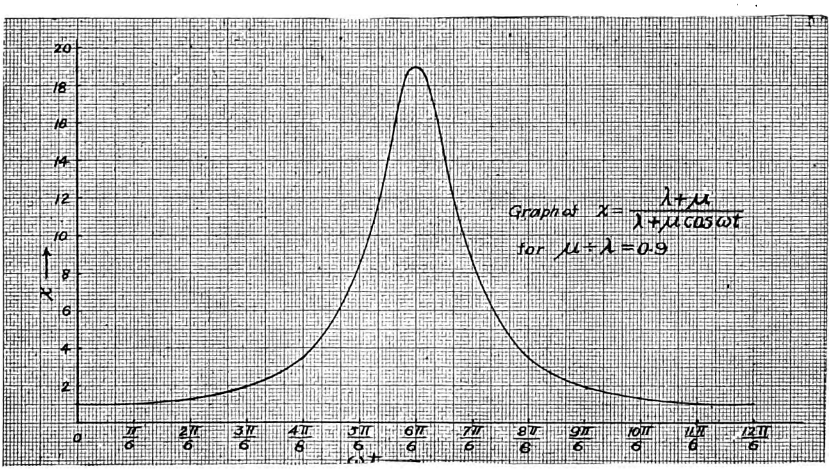


FIGURE 2

where $X = 1$, $\lambda = 1$, $\mu = 0.9$. Since it is an even function, it is developable into a series of cosines. Carrying out the development we obtain

$$x = \frac{(\lambda + \mu) X}{\lambda + \mu \cos \omega t} = 2 X \sqrt{\frac{\lambda + \mu}{\lambda - \mu}} \left( \frac{1}{2} + B \cos \omega t + B^2 \cos 2 \omega t + B^3 \cos 3 \omega t + \dots \dots \right),$$

where $$B = \sqrt{\left(\frac{\lambda}{\mu}\right)^2 - 1} - \frac{\lambda}{\mu} = \frac{\lambda}{\mu}\left(\sqrt{1 - \frac{\mu^2}{\lambda^2}} - 1\right).$$

Now, the inductance of a circuit without capacity can never become negative, hence

$$L_1 + L_2 + 2M \cos \omega t > 0,$$

$$\therefore \qquad L_1 + L_2 > 2M \text{ and } \lambda > \mu.$$

Hence B is a negative quantity whose absolute value lies between 0 and 1. B is 0 when M is 0, and $B = -1$ when $L_1 + L_2 = 2M$; i. e., when $\lambda = \mu$. This can never happen, but if it did, we see that the amplitudes of all the harmonics of x would be equal but would alternate in sign, and the series would not be convergent. In all other cases we see that the amplitudes of the higher harmonics *decrease in geometric progression*, and that they alternate in sign as before. Obviously the series is convergent.

The case just considered is a purely hypothetical one, of course, but I have worked it out in some detail because of the light it throws on the difficult problem presented by the actual circuits.

For the benefit of those who are not familiar with the theory of transformation of equations, a few words on this topic may be said. Suppose we have an equation of any nature whatever, in any number of variables. To fix the ideas, let there be two variables, x and y, and let the equation be given by

$$f(x, y) = 0.$$

To aid in solving this equation we may substitute for x any legitimate function in any number of new variables, and likewise for y. Suppose these transformations involve 2n new variables; upon $(2n - 2)$ of them we may impose any conditions we please; this leaves two variables, the relation between which must be determined from the original equation, $f(x, y) = 0$.

## CIRCUITS HAVING INDUCTANCE, RESISTANCE, AND VARIABLE MUTUAL INDUCTANCE

Turning now to Pupin's theory, we consider first the case of a circuit having resistance R, inductance L, and a constant impressed e. m. f., E.; in the field of this circuit is rotated another circuit having resistance S and inductance N. For any angle $\theta$ between the coils, the mutual inductance is given by $M \cos \theta$. (See Figure 3.) In the first circuit, the reactions are the inductance reaction $L \frac{dx}{dt}$, the resistance reaction Rx, and the e. m. f., $M \frac{d}{dt}(y \cos \omega t)$ due to the presence of the rotating circuit. In this latter the reactions are the inductance reaction

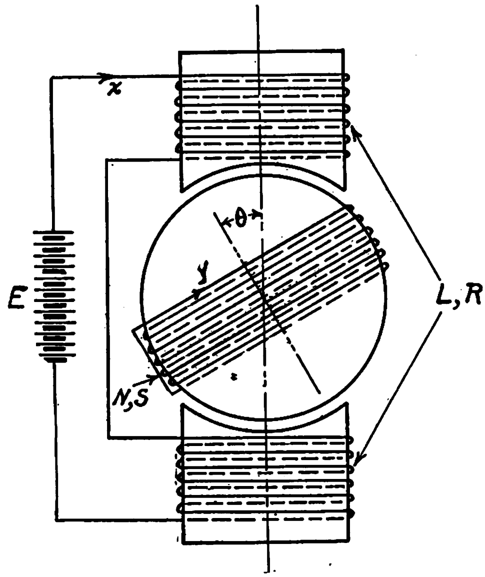


FIGURE 3

$N\frac{dy}{dt}$, the resistance reaction $Sy$, and the e. m. f. due to the presence of the stator circuit, $M\frac{d}{dt}(x \cos \omega t)$. (Thruout this paper, x shall denote the current in the stator, y the current in the rotor, and $\omega$ the angular velocity of rotation.) The equations of reactions therefore are:

$$(1) \left\{ \begin{aligned} L\frac{dx}{dt} + Rx + M\frac{d}{dt}(y \cos \omega t) &= E, \\ N\frac{dy}{dt} + Sy + M\frac{d}{dt}(x \cos \omega t) &= 0. \end{aligned} \right.$$

Pupin's rigorous solution of these equations is the backbone of his theory. Having once obtained the solution of these equations, it is a relatively simple matter to extend the theory to more complicated cases, e. g., with condensers in one or both circuits, impressed e. m. f.'s varying periodically with the time, etc. We shall treat in some detail, therefore, the case now under consideration.

To equations (1) apply the transformations:

$$(2) \left\{ \begin{aligned} x &= x_0 + x_2 + x_4 + x_6 + \ldots\ldots\ldots\ldots, \\ y &= y_1 + y_3 + y_5 + y_7 + \ldots\ldots\ldots\ldots, \end{aligned} \right.$$

getting:

$$(3)\left\{\begin{aligned}
&L\frac{dx_0}{dt}+Rx_0\\
&+L\frac{dx_2}{dt}+Rx_2+M\frac{d}{dt}(y_1\cos\omega t)\\
&+L\frac{dx_4}{dt}+Rx_4+M\frac{d}{dt}(y_3\cos\omega t)\\
&+L\frac{dx_6}{dt}+Rx_6+M\frac{d}{dt}(y_5\cos\omega t)\\
&+\,.\quad.\quad.\quad.\quad.\\
&+\,.\quad.\quad.\quad.\quad.=E,\\
&N\frac{dy_1}{dt}+Sy_1+M\frac{d}{dt}(x_0\cos\omega t)\\
&+N\frac{dy_3}{dt}+Sy_3+M\frac{d}{dt}(x_2\cos\omega t)\\
&+N\frac{dy_5}{dt}+Sy_5+M\frac{d}{dt}(x_4\cos\omega t)\\
&+\,.\quad.\quad.\quad.\quad.\\
&+\,.\quad.\quad.\quad.\quad.=0.
\end{aligned}\right.$$

We may regard this transformation as one involving the $2n+2$ variables:

$$x_0,\ x_2,\ x_4,\ \ldots\ x_{2n};\ y_1,\ y_3,\ y_5\ \ldots\ y_{2n+1};$$

where n is made to approach infinity. The transformation is therefore an infinite one, and we may impose an infinite number of arbitrary conditions; the only requirements to be fulfilled are that the sums $x_0+x_2+x_4+\ldots$ and $y_1+y_3+y_5+\ldots$ shall satisfy their respective equations and that they shall be convergent.

Impose on $x_0, y_1, x_2, y_3, x_4 \ldots$ the following conditions:

$$(4)\left\{\begin{aligned}
&(a)\quad L\frac{dx_0}{dt}+Rx_0=E\\
&\qquad(b)\quad N\frac{dy_1}{dt}+Sy_1+M\frac{d}{dt}(x_0\cos\omega t)=0\\
&(c)\quad L\frac{dx_2}{dt}+Rx_2+M\frac{d}{dt}(y_1\cos\omega t)=0\\
&\qquad(c)\quad N\frac{dy_3}{dt}+Sy_3+M\frac{d}{dt}(x_2\cos\omega t)=0\\
&(d)\quad L\frac{dx_4}{dt}+Rx_4+M\frac{d}{dt}(y_3\cos\omega t)=0\\
&\qquad(d)\quad N\frac{dy_5}{dt}+Sy_5+M\frac{d}{dt}(x_4\cos\omega t)=.0\\
&\quad.\quad.\quad.\quad.\quad.\\
&\qquad.\quad.\quad.\quad.\quad.
\end{aligned}\right.$$

These conditions obviously satisfy the transformed equations (3) for they make each part of the left-hand members of (3) vanish separately; hence they satisfy the original equations (1). Furthermore, these conditions lead to a convergent result, as will presently be shown.*

The result of the transformations (2) is to break up the original equations (1) into an infinite series of equations (4), each of which can be solved if those preceding it are solved first.

Disregarding transient states thruout, the solution of (4a) is:

$$x_0 = \frac{E}{R}. \tag{5a}$$

Substituting this in (4b) gives

$$N\frac{d y_1}{d t} + S y_1 = -M x_0 \frac{d}{d t}(\cos \omega t)$$
$$= \omega M x_0 \sin \omega t.$$

The solution of this is:

$$y_1 = \frac{\omega M x_0}{Z_1} \sin(\omega t - \theta_1)$$

$$\text{where } Z_1 = \sqrt{(\omega N)^2 + S^2} \text{ and } \theta_1 = \tan^{-1}\frac{\omega N}{S}. \tag{5b}$$

Substituting this in (4c) gives:

$$L\frac{d x_2}{d t} + R x_2 = -\frac{\omega M^2 x_0}{Z_1}\frac{d}{d t}\left[\frac{1}{2}\left(\sin(2\omega t - \theta_1) - \sin\theta_1\right)\right]$$
$$= -\frac{(\omega M)^2 x_0}{Z_1}\cos(2\omega t - \theta_1).$$

The solution of this is:

$$\left.\begin{aligned} x_2 &= -\frac{(\omega M)^2 x_0}{Z_1 Z_2}\cos(2\omega t - \theta_1 - \theta_2), \\ &\text{where } Z_2 = \sqrt{(2\omega L)^2 + R^2} \text{ and } \theta_2 = \tan^{-1}\frac{2\omega L}{R}. \end{aligned}\right\} \tag{5c}$$

Substituting this in (4d) gives:

$$N\frac{d y_3}{d t} + S y_3 = \frac{\omega^2 M^3 x_0}{Z_1 Z_2}\frac{d}{d t}\left[\frac{1}{2}\cos(3\omega t - \theta_1 - \theta_2) + \frac{1}{2}\cos(\omega t - \theta_1 - \theta_2)\right]$$
$$= -\frac{(\omega M)^3 x_0}{Z_1 Z_2}\left[\frac{3}{2}\sin(3\omega t - \theta_1 - \theta_2) + \frac{1}{2}\sin(\omega t - \theta_1 - \theta_2)\right].$$

*Later we shall deal with a case where the series are divergent, but it will be shown that even in this case Pupin's transformation is justified by the physical phenomena.

The solution of this is:

$$
\text{(5d)}\begin{cases}
y_3 = -\dfrac{(\omega M)^3 x_o}{Z_1 Z_2}\left[\dfrac{3}{2 Z_3}\sin(3\omega t - \theta_1 - \theta_2 - \theta_3)\right. \\
\qquad\qquad\qquad\qquad \left. + \dfrac{1}{2 Z_1}\sin(\omega t - 2\theta_1 - \theta_2)\right], \\
\text{where } Z_3 = \sqrt{(3\omega N)^2 + S^2} \text{ and } \theta_3 = \tan^{-1}\dfrac{3\omega N}{S}.
\end{cases}
$$

We may continue in precisely the same manner to get $x_4, y_5, x_6, y_7, \ldots$ in turn. The complications multiply very rapidly, however, so I shall merely write down the values for a few more terms.

$$
\text{(5e)}\begin{cases}
x_4 = \dfrac{(\omega M)^4}{Z_1 Z_2} x_o\left[\dfrac{3}{Z_3 Z_4}\cos(4\omega t - \theta_1 - \theta_2 - \theta_3 - \theta_4)\right. \\
\qquad + \dfrac{3}{2 Z_2 Z_3}\cos(2\omega t - \theta_1 - 2\theta_2 - \theta_3) \\
\qquad \left. + \dfrac{1}{2 Z_1 Z_2}\cos(2\omega t - 2\theta_1 - 2\theta_2)\right], \\
\text{where } Z_4 = \sqrt{(4\omega L)^2 + R^2} \text{ and } \theta_4 = \tan^{-1}\dfrac{4\omega L}{R}.
\end{cases}
$$

$$
\text{(5f)}\begin{cases}
y_5 = \dfrac{(\omega M)^5 x_o}{Z_1 Z_2}\left[\dfrac{15}{2 Z_3 Z_4 Z_5}\sin(5\omega t - \theta_1 - \theta_2 - \theta_3 - \theta_4 - \theta_5)\right. \\
\qquad\qquad + \dfrac{9}{2 Z_3^2 Z_4}\sin(3\omega t - \theta_1 - \theta_2 - 2\theta_3 - \theta_4) \\
+ \dfrac{9}{4 Z_2 Z_3^2}\sin(3\omega t - \theta_1 - 2\theta_2 - 2\theta_3) \\
\qquad\qquad + \dfrac{3}{4 Z_1 Z_2 Z_3}\sin(3\omega t - 2\theta_1 - 2\theta_2 - \theta_3) \\
+ \dfrac{3}{4 Z_1 Z_2 Z_3}\sin(\omega t - 2\theta_1 - 2\theta_2 - \theta_3) \\
\qquad\qquad \left. + \dfrac{1}{4 Z_1^2 Z_2}\sin(\omega t - 3\theta_1 - 2\theta_2)\right], \\
\text{where } Z_5 = \sqrt{(5\omega N)^2 + S^2} \text{ and } \theta_5 = \tan^{-1}\dfrac{5\omega N}{S}.
\end{cases}
$$

$$
(5g)\left\{\begin{aligned}
x_6 = &-\frac{(\omega M)^6 x_o}{Z_1 Z_2}\left[\frac{45}{2 Z_3 Z_4 Z_5 Z_6}\cos(6\omega t-\theta_1-\theta_2-\theta_3-\theta_4\right.\\
&-\theta_5-\theta_6)+\frac{15}{Z_3 Z_4^2 Z_5}\cos(4\omega t-\theta_1-\theta_2-\theta_3-2\theta_4-\theta_5)\\
&+\frac{9}{Z_3^2 Z_4^2}\cos(4\omega t-\theta_1-\theta_2-2\theta_3-2\theta_4)\\
&\qquad+\frac{9}{2 Z_2 Z_3^2 Z_4}\cos(4\omega t-\theta_1-2\theta_2-2\theta_3-\theta_4)\\
&+\frac{3}{2 Z_1 Z_2 Z_3 Z_4}\cos(4\omega t-2\theta_1-2\theta_2-\theta_3-\theta_4)\\
&\qquad+\frac{9}{2 Z_2 Z_3^2 Z_4}\cos(2\omega t-\theta_1-2\theta_2-2\theta_3-\theta_4)\\
&+\frac{9}{4 Z_2^2 Z_3^2}\cos(2\omega t-\theta_1-3\theta_2-2\theta_3)\\
&\qquad+\frac{3}{2 Z_1 Z_2^2 Z_3}\cos(2\omega t-2\theta_1-3\theta_2-\theta_3)\\
&\left.+\frac{1}{4 Z_1^2 Z_2^2}\cos(2\omega t-3\theta_1-3\theta_2)\right],\\
&\text{where } Z_6=\sqrt{(6\omega L)^2+R^2} \text{ and } \theta_6=\tan^{-1}\frac{6\omega L}{R}.
\end{aligned}\right.
$$

We see, therefore, that the current $y_1$ contains the frequency $\frac{\omega}{2\pi}$, the current $x_2$ the frequency $\frac{2\omega}{2\pi}$, the current $y_3$ the frequencies $\frac{3\omega}{2\pi}$ and $\frac{\omega}{2\pi}$, the current $x_4$ the frequencies $\frac{4\omega}{2\pi}$ and $\frac{2\omega}{2\pi}$, the current $y_5$ the frequencies $\frac{5\omega}{2\pi}$, $\frac{3\omega}{2\pi}$ and $\frac{\omega}{2\pi}$; etc. That is, the current $y_{2n+1}$ contains all the odd frequencies from $(2n+1)\frac{\omega}{2\pi}$ down to $\frac{\omega}{2\pi}$, and the current $x_{2n}$ all the even frequencies from $\frac{2n\omega}{2\pi}$ down to $\frac{2\omega}{2\pi}$. If we collect all the terms of frequency $\frac{\omega}{2\pi}$ and denote the result by $\eta_1$, those of frequency $\frac{2\omega}{2\pi}$ and denote the result by $\xi_2$, etc., we get:

$$
\begin{aligned}
(6a)\quad \eta_1 = &\frac{\omega M x_o}{Z_1}\sin(\omega t-\theta_1)-\frac{(\omega M)^3 x_o}{2 Z_1^2 Z_2}\sin(\omega t-2\theta_1-\theta_2)\\
&+\frac{3(\omega M)^5 x_o}{4 Z_1^2 Z_2^2 Z_3}\sin(\omega t-2\theta_1-2\theta_2-\theta_3)\\
&\qquad+\frac{(\omega M)^5 x_o}{4 Z_1^3 Z_2^2}\sin(\omega t-3\theta_1-2\theta_2)
\end{aligned}
$$

$$-\frac{9\,(\omega M)^7\,x_0}{4\,Z_1^2\,Z_2^2\,Z_3^2\,Z_4}\sin(\omega t-2\,\theta_1-2\,\theta_2-2\,\theta_3-\theta_4)$$

$$-\frac{9\,(\omega M)^7 x_0}{8\,Z_1^2 Z_2^3\,Z_3^2}\sin(\omega t-2\,\theta_1-3\,\theta_2-2\,\theta_3)$$

$$-\frac{3\,(\omega M)^7\,x_0}{4\,Z_1^3\,Z_2^3\,Z_3}\sin(\omega t-3\,\theta_1-3\,\theta_2-\theta_3)$$

$$-\frac{(\omega M)^7\,x_0}{8\,Z_1^4\,Z_2^3}\sin(\omega t-4\,\theta_1-3\,\theta_2)$$

$$+\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot$$

$$+\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot$$

(6b) $$\xi_2=-\frac{(\omega M)^2\,x_0}{Z_1\,Z_2}\cos(2\,\omega t-\theta_1-\theta_2)$$

$$+\frac{3\,(\omega M)^4\,x_0}{2\,Z_1\,Z_2^2\,Z_3}\cos(2\,\omega t-\theta_1-2\,\theta_2-\theta_3)$$

$$+\frac{(\omega M)^4\,x_0}{2\,Z_1^2\,Z_2^2}\cos(2\,\omega t-2\,\theta_1-2\,\theta_2)$$

$$-\frac{9\,(\omega M)^6\,x_0}{2\,Z_1\,Z_2^2\,Z_3^2\,Z_4}\cos(2\,\omega t-\theta_1-2\,\theta_2-2\,\theta_3-\theta_4)$$

$$-\frac{9\,(\omega M)^6\,x_0}{4\,Z_1\,Z_2^3\,Z_3^2}\cos(2\,\omega t-\theta_1-3\,\theta_2-2\,\theta_3)$$

$$-\frac{3\,(\omega M)^6 x_0}{2\,Z_1^2\,Z_2^3\,Z_3}\cos(2\,\omega t-2\theta_1-3\,\theta_2-\theta_3)$$

$$-\frac{(\omega M)^6\,x_0}{4\,Z_1^3\,Z_2^3}\cos(2\,\omega t-3\,\theta_1-3\,\theta_2)+\quad\cdot\quad\cdot$$

$$+\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot$$

(6c) $$\eta_3=-\frac{3\,(\omega M)^3\,x_0}{2\,Z_1\,Z_2\,Z_3}\sin(3\,\omega t-\theta_1-\theta_2-\theta_3)$$

$$+\frac{9\,(\omega M)^5\,x_0}{2\,Z_1 Z_2 Z_3^2 Z_4}\sin(3\,\omega t-\theta_1-\theta_2-2\,\theta_3-\theta_4)$$

$$+\frac{9\,(\omega M)^5\,x_0}{4\,Z_1\,Z_2^2\,Z_3^2}\sin(3\,\omega t-\theta_1-2\,\theta_2-2\,\theta_3)$$

$$+\frac{3\,(\omega M)^5\,x_0}{4\,Z_1^2\,Z_2^2\,Z_3}\sin(3\,\omega t-2\,\theta_1-2\,\theta_2-\theta_3)$$

$$-\frac{45\,(\omega M)^7\,x_0}{2\,Z_1\,Z_2\,Z_3^2\,Z_4^2\,Z_5}\sin(3\,\omega t-\theta_1-\theta_2-2\,\theta_3-2\,\theta_4-\theta_5)$$

$$-\frac{27\,(\omega M)^7\,x_0}{2\,Z_1\,Z_2\,Z_3^3\,Z_4^2}\sin(3\,\omega t-\theta_1-\theta_2-3\,\theta_3-2\,\theta_4)$$

$$- \frac{27\,(\omega M)^7\,x_o}{2\,Z_1\,Z_2^2\,Z_3^3\,Z_4} \sin(3\,\omega t - \theta_1 - 2\,\theta_2 - 3\,\theta_3 - \theta_4)$$

$$- \frac{9\,(\omega M)^7\,x_o}{4\,Z_1^2\,Z_2^2\,Z_3^2\,Z_4} \sin(3\,\omega t - 2\,\theta_1 - 2\,\theta_2 - 2\,\theta_3 - \theta_4)$$

$$- \frac{27\,(\omega M)^7\,x_o}{8\,Z_1\,Z_2^3\,Z_3^3} \sin(3\,\omega t - \theta_1 - 3\,\theta_2 - 3\,\theta_3)$$

$$- \frac{9\,(\omega M)^7\,x_o}{4\,Z_1^2\,Z_2^3\,Z_3^2} \sin(3\,\omega t - 2\,\theta_1 - 3\,\theta_2 - 2\,\theta_3)$$

$$- \frac{3\,(\omega M)^7\,x_o}{8\,Z_1^3\,Z_2^3\,Z_3} \sin(3\,\omega t - 3\,\theta_1 - 3\,\theta_2 - \theta_3)$$

$$+ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$+ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$\text{(6d)} \quad \xi_4 = \frac{3\,(\omega M)^4\,x_o}{Z_1\,Z_2\,Z_3\,Z_4} \cos(4\,\omega t - \theta_1 - \theta_2 - \theta_3 - \theta_4)$$

$$- \frac{15\,(\omega M)^6\,x_o}{Z_1\,Z_2\,Z_3\,Z_4^2\,Z_5} \cos(4\,\omega t - \theta_1 - \theta_2 - \theta_3 - 2\,\theta_4 - \theta_5)$$

$$- \frac{9\,(\omega M)^6\,x_o}{Z_1\,Z_2\,Z_3^2\,Z_4^2} \cos(4\,\omega t - \theta_1 - \theta_2 - 2\,\theta_3 - 2\,\theta_4)$$

$$- \frac{9\,(\omega M)^6\,x_o}{2\,Z_1\,Z_2^2\,Z_3^2\,Z_4} \cos(4\,\omega t - \theta_1 - 2\,\theta_2 - 2\,\theta_3 - \theta_4)$$

$$- \frac{3\,(\omega M)^6\,x_o}{2\,Z_1^2\,Z_2^2\,Z_3\,Z_4} \cos(4\,\omega t - 2\,\theta_1 - 2\,\theta_2 - \theta_3 - \theta_4)$$

$$+ \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$+ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$\text{(6e)} \quad \eta_5 = \frac{15\,(\omega M)^5\,x_o}{2\,Z_1\,Z_2\,Z_3\,Z_4\,Z_5} \sin(5\,\omega t - \theta_1 - \theta_2 - \theta_3 - \theta_4 - \theta_5)$$

$$- \frac{225\,(\omega M)^7\,x_o}{4\,Z_1\,Z_2\,Z_3\,Z_4\,Z_5^2\,Z_6} \sin(5\omega t - \theta_1 - \theta_2 - \theta_3 - \theta_4 - 2\,\theta_5 - \theta_6)$$

$$- \frac{75\,(\omega M)^7\,x_o}{2\,Z_1\,Z_2\,Z_3\,Z_4^2\,Z_5^2} \sin(5\,\omega t - \theta_1 - \theta_2 - \theta_3 - 2\,\theta_4 - 2\,\theta_5)$$

$$- \frac{45\,(\omega M)^7\,x_o}{2\,Z_1\,Z_2\,Z_3^2\,Z_4^2\,Z_5} \sin(5\,\omega t - \theta_1 - \theta_2 - 2\,\theta_3 - 2\,\theta_4 - \theta_5)$$

$$- \frac{45\,(\omega M)^7\,x_o}{4\,Z_1\,Z_2^2\,Z_3^2\,Z_4\,Z_5} \sin(5\,\omega t - \theta_1 - 2\,\theta_2 - 2\,\theta_3 - \theta_4 - \theta_5)$$

$$- \frac{15\,(\omega M)^7\,x_o}{4\,Z_1^2\,Z_2^2\,Z_3\,Z_4\,Z_5} \sin(5\,\omega t - 2\,\theta_1 - 2\,\theta_2 - \theta_3 - \theta_4 - \theta_5)$$

$$+ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

(6f) $\xi_6 = -\frac{45\,(\omega M)^6 x_o}{2\,Z_1 Z_2 Z_3 Z_4 Z_5 Z_6}\cos(6\,\omega t - \theta_1 - \theta_2 - \theta_3 - \theta_4 - \theta_5 - \theta_6)$

$+ \ldots$

(6g) $\eta_7 = -\frac{7 \times 45\,(\omega M)^7 x_o}{4\,Z_1 Z_2 Z_3 Z_4 Z_5 Z_6 Z_7}\sin(7\,\omega t - \theta_1 - \theta_2 - \theta_3 - \theta_4 - \theta_5 - \theta_6 - \theta_7) + \ldots$

. . . . . . .

. . . . . . .

Finally

$$
\begin{aligned}
x &= x_o + \xi_2 + \xi_4 + \xi_6 + \xi_8 + \ldots \\
y &= \quad\;\;\; \eta_1 + \eta_3 + \eta_5 + \eta_7 + \ldots
\end{aligned} \tag{7}
$$

These series are Pupin's solution of the fundamental differential equations (1). They are, in effect, Fourier's series, each amplitude of which is an infinite series. Their physical significance is most easily brought out after their convergence has been demonstrated.

### PROOF OF CONVERGENCE WITH VANISHINGLY SMALL RESISTANCES

I have found a relatively simple proof of the convergence by first letting the resistances become vanishingly small, which leads us to series that are obviously convergent, and then showing that the re-introduction of finite resistances does not affect the convergence.

When $R = S = 0$, $\quad \theta_1 = \theta_2 = \theta_3 = \ldots = \frac{\pi}{2}$,

and $Z_1 = \omega N$, $Z_2 = 2\,\omega L$, $Z_3 = 3\,\omega N$, $Z_4 = 4\,\omega L, \ldots$

Hence $\eta_1$ becomes

$$
\begin{aligned}
\eta_1 = x_o \frac{M}{N}\Bigg\{ & \sin\left(\omega t - \frac{\pi}{2}\right) - \frac{M^2}{4\,L N}\sin\left(\omega t - \frac{3\pi}{2}\right) \\
& + \frac{3}{4 \times 4 \times 3}\left(\frac{M^2}{L N}\right)^2 \sin\left(\omega t - \frac{5\pi}{2}\right) + \frac{1}{4 \times 4}\left(\frac{M^2}{L N}\right)^2 \sin\left(\omega t - \frac{5\pi}{2}\right) \\
& - \frac{9}{4 \times 4 \times 9 \times 4}\left(\frac{M^2}{L N}\right)^3 \sin\left(\omega t - \frac{7\pi}{2}\right) \\
& \qquad\qquad - \frac{9}{8 \times 8 \times 9}\left(\frac{M^2}{L N}\right)^3 \sin\left(\omega t - \frac{7\pi}{2}\right) \\
& - \frac{3}{4 \times 8 \times 3}\left(\frac{M^2}{L N}\right)^3 \sin\left(\omega t - \frac{7\pi}{2}\right) - \frac{1}{8 \times 8}\left(\frac{M^2}{L N}\right)^3 \sin\left(\omega t - \frac{7\pi}{2}\right) \\
& + \ldots \Bigg\}
\end{aligned}
$$

Hence:

$$
(8)\quad
\begin{cases}
\eta_1 = -x_0 \dfrac{M}{N} \cos \omega t \left\{ 1 + \dfrac{1}{2^2}\left(\dfrac{M^2}{LN}\right) + \dfrac{2}{2^4}\left(\dfrac{M^2}{LN}\right)^2 + \dfrac{5}{2^6}\left(\dfrac{M^2}{LN}\right)^3 + \cdots \right\} \\
\text{Similarly} \\
\xi_2 = \dfrac{x_0}{2}\left(\dfrac{M^2}{LN}\right) \cos 2\omega t \left\{ 1 + \dfrac{2}{2^2}\left(\dfrac{M^2}{LN}\right) + \dfrac{5}{2^4}\left(\dfrac{M^2}{LN}\right)^2 + \dfrac{14}{2^6}\left(\dfrac{M^2}{LN}\right)^3 + \cdots \right\} \\
\eta_3 = -\dfrac{x_0}{2^2}\dfrac{M}{N}\left(\dfrac{M^2}{LN}\right) \cos 3\omega t \left\{ 1 + \dfrac{3}{2^2}\left(\dfrac{M^2}{LN}\right) + \dfrac{9}{2^4}\left(\dfrac{M^2}{LN}\right)^2 + \dfrac{28}{2^6}\left(\dfrac{M^2}{LN}\right)^3 + \cdots \right\} \\
\xi_4 = \dfrac{x_0}{2^3}\left(\dfrac{M^2}{LN}\right)^2 \cos 4\omega t \left\{ 1 + \dfrac{4}{2^2}\left(\dfrac{M^2}{LN}\right) + \dfrac{14}{2^4}\left(\dfrac{M^2}{LN}\right)^2 + \dfrac{48}{2^6}\left(\dfrac{M^2}{LN}\right)^3 + \cdots \right\} \\
\eta_5 = -\dfrac{x_0}{2^4}\dfrac{M}{N}\left(\dfrac{M^2}{LN}\right)^2 \cos 5\omega t \left\{ 1 + \dfrac{5}{2^2}\left(\dfrac{M^2}{LN}\right) + \dfrac{20}{2^4}\left(\dfrac{M^2}{LN}\right)^2 + \dfrac{75}{2^6}\left(\dfrac{M^2}{LN}\right)^3 + \cdots \right\} \\
\xi_6 = \dfrac{x_0}{2^5}\left(\dfrac{M^2}{LN}\right)^3 \cos 6\omega t \left\{ 1 + \dfrac{6}{2^2}\left(\dfrac{M^2}{LN}\right) + \cdots \right\} \\
\cdots\cdots
\end{cases}
$$

Now, by expansion in power series we find:

$$
(9)\quad
\begin{cases}
\left(1 - \sqrt{1 - \dfrac{M^2}{LN}}\right) = \dfrac{1}{2}\left(\dfrac{M^2}{LN}\right)\left\{ 1 + \dfrac{1}{2^2}\left(\dfrac{M^2}{LN}\right) + \dfrac{2}{2^4}\left(\dfrac{M^2}{LN}\right)^2 + \dfrac{5}{2^6}\left(\dfrac{M^2}{LN}\right)^3 + \cdots \right. \\
\left(1 - \sqrt{1 - \dfrac{M^2}{LN}}\right)^2 = \dfrac{1}{2^2}\left(\dfrac{M^2}{LN}\right)^2\left\{ 1 + \dfrac{2}{2^2}\left(\dfrac{M^2}{LN}\right) + \dfrac{5}{2^4}\left(\dfrac{M^2}{LN}\right)^2 + \dfrac{14}{2^6}\left(\dfrac{M^2}{LN}\right)^3 + \cdots \right\} \\
\left(1 - \sqrt{1 - \dfrac{M^2}{LN}}\right)^3 = \dfrac{1}{2^3}\left(\dfrac{M^2}{LN}\right)^3\left\{ 1 + \dfrac{3}{2^2}\left(\dfrac{M^2}{LN}\right) + \dfrac{9}{2^4}\left(\dfrac{M^2}{LN}\right)^2 + \dfrac{28}{2^6}\left(\dfrac{M^2}{LN}\right)^3 + \cdots \right\}
\end{cases}
$$

$$\left(1-\sqrt{1-\frac{M^2}{LN}}\right)^4=\frac{1}{2^4}\left(\frac{M^2}{LN}\right)^4\left\{1+\frac{4}{2^2}\left(\frac{M^2}{LN}\right)+\frac{14}{2^4}\left(\frac{M^2}{LN}\right)^2\right.$$
$$\left.+\frac{48}{2^6}\left(\frac{M^2}{LN}\right)^3+\cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\right\}$$
$$\cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot$$

From (8) and (9) there results:

$$\eta_1=-2x_o\frac{L}{M}\left(1-\sqrt{1-\frac{M^2}{LN}}\right)\cos\omega t$$
$$\xi_2=2x_o\frac{LN}{M^2}\left(1-\sqrt{1-\frac{M^2}{LN}}\right)^2\cos 2\omega t$$
$$\eta_3=-2x_o\frac{L}{M}\left(\frac{LN}{M^2}\right)\left(1-\sqrt{1-\frac{M^2}{LN}}\right)^3\cos 3\omega t$$
$$\xi_4=2x_o\left(\frac{LN}{M^2}\right)^2\left(1-\sqrt{1-\frac{M^2}{LN}}\right)^4\cos 4\omega t$$
$$\eta_5=-2x_o\frac{L}{M}\left(\frac{LN}{M^2}\right)^2\left(1-\sqrt{1-\frac{M^2}{LN}}\right)^5\cos 5\omega t$$
$$\cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot$$

$$\cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot$$

Hence, putting for brevity:

$$\left(\frac{LN}{M^2}\right)\left(1-\sqrt{1-\frac{M^2}{LN}}\right)^2=\phi$$

we get

$$(10)\quad\left\{\begin{aligned}x&=x_o+2x_o\left\{\phi\cos 2\omega t+\phi^2\cos 4\omega t+\phi^3\cos 6\omega t\right.\\&\qquad\left.+\cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\right\}\\y&=-2x_o\frac{L}{M}\left(1-\sqrt{1-\frac{M^2}{LN}}\right)\left\{\cos\omega t+\phi\cos 3\omega t\right.\\&\qquad\left.+\phi^2\cos 5\omega t+\phi^3\cos 7\omega t+\cdot\ \cdot\ \cdot\ \cdot\ \cdot\right\}.\end{aligned}\right.$$

Hence Pupin's series reduce to Fourier's series, the amplitudes of which are proportional to integral powers of $\phi$. This is what we should expect from the simple case treated above of a single circuit with no resistance and a periodically varied self-induction. In fact, if we had chosen in the case first treated, a pair of circuits with periodically varied mutual inductance and no resistance,

instead of a single circuit with periodically varied self-inductance, we should have arrived immediately at equations (10).

The quantity $\phi$ takes the form $\infty \times 0$ when $M = 0$, and so does the quantity $\frac{L}{M}\left(1 - \sqrt{1 - \frac{M^2}{LN}}\right)$. It may readily be shown, however, that

$$\lim_{M \doteq 0} \phi = 0$$

and that $$\lim_{M \doteq 0} \frac{L}{M}\left(1 - \sqrt{1 - \frac{M^2}{LN}}\right) = 0$$

Hence, when $M = 0$, the only current which exists is $x_0 = E/R$, which, of course, must be the case. Further, $\frac{M^2}{LN}$ is the coupling factor of the two circuits, and this must always be less than unity, and positive, of course. With these limitations on $\frac{M_2}{LN}$, it is clear that the quantities $\phi$ and $\left(1 - \sqrt{1 - \frac{M^2}{LN}}\right)$ can never reach unity. Therefore

$$0 < \phi < 1 \text{ and } 0 < \left(1 - \sqrt{1 - \frac{M^2}{LN}}\right) < 1.$$

Hence the amplitudes of equations (10) are power series whose ratio is less than unity in absolute value, therefore the series are absolutely convergent.

## PROOF OF CONVERGENCE WITH FINITE RESISTANCES

This result will now be extended to the practical case where the resistances are finite. In order to pass from equations (10) back to equations (7) and (6), we go through the following steps: (1), expand each expression $2\phi^n$ and $2\frac{L}{M}\left(1 - \sqrt{1 - \frac{M^2}{LN}}\right)\phi^n$ into power series in $\left(\frac{M^2}{LN}\right)$; (2), break up each term $h\left(\frac{M^2}{LN}\right)^k$ of the resulting series into a number of smaller terms

$$a_1\left(\frac{M^2}{LN}\right)^k + a_2\left(\frac{M^2}{LN}\right)^k + a_3\left(\frac{M^2}{LN}\right)^k + \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

where $a_1$, $a_2$, $a_3$, . . . all have the same sign as the original term $h\left(\frac{M^2}{LN}\right)^k$; (it is important to note that in forming equations (8), the terms which were combined into single terms all

had the same sign); (3), split up each term $a_i\left(\frac{M^2}{LN}\right)^k \cos m\,\omega t$ into two terms, viz.,

$$a_i\left(\frac{M^2}{LN}\right)^k \sin\Theta \cos m\,\omega t \quad \text{and} \quad a_i\left(\frac{M^2}{LN}\right)^k \cos\Theta \sin m\,\omega t,$$

each of which is smaller than the term from which it is derived. In this way each of the series in equations (10) is converted into two series, one in sines, the other in cosines, in each of which the amplitudes are infinite series. That is, we pass from the convergent series of (10) to Pupin's series (8) by a number of steps *which cannot alter the convergence.* Hence it is proved that Pupin's series are convergent, and therefore that the Pupin theory is entirely rigorous.

## PHYSICAL INTERPRETATION OF THE SOLUTION

Turning now to the physical interpretation of equations (6) and (7), we see that whenever an asymetrical rotor is revolved in the field of a stator on which is impressed a constant e. m. f., there are generated an infinite number of harmonics in both the stator and the rotor. The harmonics in the rotor are all odd, in the stator they are all even. If the resistances are small in comparison with the inductances, the amplitudes of the harmonics decrease approximately according to integral powers of a quantity $\phi$ whose absolute value is less than unity. If the resistances are not small, it is obvious that amplitudes must decrease more rapidly. The smaller the coupling coefficient the smaller is the quantity $\phi$, and hence the more rapidly do the amplitudes decrease. The wave distortion in single phase alternators is an example; if the air gap is small, the coupling $\frac{M^2}{LN}$ will not be very small, and the amplitudes of the odd harmonics in the rotor will not fall off very rapidly. The presence of these odd harmonics constitutes at least part of the distortion. If a large uncoupled inductance is connected in series with the field of a single phase alternator, the coupling $\frac{M^2}{LN}$ will be reduced, and the distortion consequently diminished. This might be of practical importance, for example, in enabling single phase alternators to be constructed with smaller air gaps and thereby reducing the amount of copper required in the field coils. The case of polyphase alternators with unbalanced load is precisely similar, of course.

In ordinary alternating current machinery, the harmonics are suppressed as far as possible; in the Goldschmidt alternator, on the other hand, the harmonics are encouraged by the use of condensers, the object being to get as much energy as possible into a single predetermined overtone. In his lectures, Professor Pupin indicated how the theory could be extended to include condensers in the stator and rotor circuits. This extension will now be carried out in detail.

## CIRCUITS HAVING RESISTANCE, INDUCTANCE, CAPACITY AND VARIABLE MUTUAL INDUCTANCE

Suppose that the rotor and stator circuits include any arbitrary arrangement of inductances and capacities. At a given frequency $\frac{2n\omega}{2\pi}$, the stator circuit will have a definite effective resistance, which we may denote by $R_{2n}$, and a definite effective inductance, which we may denote by $L_{2n}$. Similarly, at a given frequency $\frac{(2n+1)\omega}{2\pi}$, the rotor circuit will have an effective resistance $S_{2n+1}$ and inductance $N_{2n+1}$. That is, the quantities R, S, L, N are no longer constants, but are functions of the frequency. $R_{2n}$ and $S_{2n+1}$ must always be positive, but $L_{2n}$ and $N_{2n+1}$ may be positive, negative or zero. If $L_{2n} = 0$, it means that the stator circuit is tuned to the frequency $\frac{2n\omega}{2\pi}$; similarly, if $N_{2n+1} = 0$, the rotor circuit is tuned to the frequency $\frac{(2n+1)\omega}{2\pi}$.

It is clear, therefore, that the fundamental differential equations (1) hold for the present case as well as for the previous case, provided that we consider steady states only, the only difference being that R, S, L and N are now functions of $\omega$. Bearing this in mind we may proceed exactly in the same manner as before, arriving at equations (4). The solutions of these equations are of the same form as in the previous case, i. e., of the same form as equations (5); but now, $Z_1$, $Z_2$, $Z_3$, $Z_4$ . . . . and $\theta_1$, $\theta_2$, $\theta_3$, $\theta_4$, . . . . are given by:

$$Z_1^2 = (\omega N_1)^2 + S_1^2 \qquad \theta_1 = \tan^{-1}\frac{\omega N_1}{S_1}$$

$$Z_2^2 = (2\omega L_2)^2 + R_2^2 \qquad \theta_2 = \tan^{-1}\frac{2\omega L_2}{R_2}$$

$$Z_3^2 = (3\omega N_3)^2 + S_3^2 \qquad \theta_3 = \tan^{-1}\frac{3\omega N_3}{S_3}$$

$$Z_4^2 = (4\,\omega L_4)^2 + R_4^2 \qquad \theta_4 = \tan^{-1}\frac{4\,\omega L_4}{R_4}$$

. . . . . . . . . . . . . . .

It is clear, therefore, that the solutions as given by equations (6) and (7) hold for all cases, provided that the proper meanings be attached to the Z's and the $\theta$'s.

We proceed now to investigate what happens to Pupin's series when the rotor circuit is tuned to a definite number of frequencies $\frac{\omega}{2\pi}, \frac{3\,\omega}{2\pi}\ldots$, and the stator circuit to the frequencies $\frac{2\,\omega}{2\pi}, \frac{4\,\omega}{2\pi}, \ldots$ To fix the ideas, let the rotor be tuned to the single frequency $\frac{\omega}{2\pi}$, and the stator to the single frequency $\frac{2\,\omega}{2\pi}$. Then $Z_1$ becomes simply $S_1$, and $Z_2$ becomes $R_2$. We assume, furthermore, that the effective resistances for these frequencies, i. e., $S_1$ and $R_2$, are small. Then the quantities $\frac{\omega M}{Z_1}$ and $\frac{\omega M}{Z_2}$, which now become $\frac{\omega M}{S_1}$ and $\frac{\omega M}{R_2}$, are very large.

It will be observed that the current $\eta_1$ contains the amplitudes:

$$\frac{\omega M x_o}{Z_1},\ \left(\frac{\omega M}{Z_1}\right)^2\left(\frac{\omega M}{2\,Z_2}\right)x_o,\ \left(\frac{\omega M}{Z_1}\right)^3\left(\frac{\omega M}{2\,Z_2}\right)^2 x_o,\ \left(\frac{\omega M}{Z_1}\right)^4\left(\frac{\omega M}{2\,Z_2}\right)^3 x_o$$
$$\left(\frac{\omega M}{Z_1}\right)^5\left(\frac{\omega M}{2\,Z_2}\right)^4 x_o, \ldots$$

Likewise, the current $\xi_2$ contains the amplitudes:

$$2\,x_o\left(\frac{\omega M}{Z_1}\right)\left(\frac{\omega M}{2\,Z_2}\right),\ 2\,x_o\left(\frac{\omega M}{Z_1}\right)^2\left(\frac{\omega M}{2\,Z_2}\right)^2,\ 2\,x_o\left(\frac{\omega M}{Z_1}\right)^3\left(\frac{\omega M}{2\,Z_2}\right)^3.$$
$$2\,x_o\left(\frac{\omega M}{Z_1}\right)^4\left(\frac{\omega M}{2\,Z_2}\right)^4, \ldots$$

and $\eta_3$ contains the amplitudes:

$$\frac{3\,\omega M x_o}{Z_3}\left(\frac{\omega M}{Z_1}\right)\left(\frac{\omega M}{2\,Z_2}\right),\ \frac{3\,\omega M x_o}{Z_3}\left(\frac{\omega M}{Z_1}\right)^2\left(\frac{\omega M}{2\,Z_2}\right)^2,$$
$$\frac{3\,\omega M x_o}{Z_3}\left(\frac{\omega M}{Z_1}\right)^3\left(\frac{\omega M}{2\,Z_2}\right)^3, \ldots$$

and $\xi_4$ contains the amplitudes:

$$\frac{6\,(\omega M)^2 x_o}{Z_3 Z_4}\left(\frac{\omega M}{Z_1}\right)\left(\frac{\omega M}{2\,Z_2}\right),\ \frac{6\,(\omega M)^2 x_o}{Z_3 Z_4}\left(\frac{\omega M}{Z_1}\right)^2\left(\frac{\omega M}{2\,Z_2}\right)^2$$

. . . . . . . .

We see, therefore, that every current contains amplitudes which are power series in $\left(\frac{\omega M}{Z_1}\right)\left(\frac{\omega M}{2 Z_2}\right)$; and if the circuits are tuned so as to reduce $Z_1$ to $S_1$ and $Z_2$ to $R_2$, and if these resistances are small, it follows that *all* the series of equations (6) *diverge*, and therefore that *all the amplitudes tend towards infinity.* A complete discussion of the convergence or divergence of these series is not very simple, but in the given case it is clear that if the resistances $R_2$ and $S_1$, are small, the higher powers of $\left(\frac{\omega M}{Z_1}\right)\left(\frac{\omega M}{2 Z_2}\right)$ which occur in all the amplitudes soon become so large as to make all the other terms in the amplitudes negligibly small, and the divergence of all the amplitudes is therefore assured.

## EXPLANATION OF LIMITATION OF ROTOR AND STATOR CURRENTS IN PRACTICE

The question now arises, does the Pupin theory break down when tuned condenser circuits of low resistance are employed, or is the theory still justified by the physical phenomena? And if the theory is justified how can the operation of the Goldschmidt alternator be accounted for?

The answer to both of these questions is, I think, not far to seek. It does not require an elaborate theory to show that if the stator and rotor circuits are tuned, let us say to the frequencies $\frac{2\omega}{2\pi}$ and $\frac{\omega}{2\pi}$ respectively, the currents all tend toward infinity in an ideal machine of low resistance. For, suppose a current $x_o$ is flowing in the stator; this will give rise to a current $\frac{\omega M x_o}{S} \sin \omega t$ in the tuned rotor circuit; this in turn will give rise to a current $-\frac{(\omega M)^2 x_o}{R S} \cos 2\omega t$ in the tuned stator circuit (leaving out of account the other currents generated): this stator current in turn will give rise to a current $-\frac{(\omega M)^3 x_o}{2 R S^2} \sin \omega t$ in the tuned rotor circuit, which is opposite in phase to the first current $\frac{\omega M x_o}{S} \sin \omega t$ but is very much larger than the same if the resistances are small. In this way, each new current of frequency $\frac{\omega}{2\pi}$ in the rotor will

give rise to a much larger current of frequency $\frac{2\omega}{2\pi}$ in the stator, and this in turn to a still larger current of frequency $\frac{\omega}{2\pi}$ in the rotor, and so forth. Physical reasoning shows, therefore, that the currents to which the circuits are tuned tend toward infinity in ideal machines of low resistance. But obviously, if one of the currents becomes infinite, they all must become infinite, hence the Pupin theory as applied to the case of tuned condenser circuits is entirely in accord with the phenomena which would exist in an ideal machine. The correctness of the Pupin theory in all cases is therefore established.

As regards the practical operation of the Goldschmidt alternator, this is readily accounted for by the variable permeability of the iron. As the rotor and stator currents become larger and larger, the permeability of the iron becomes smaller and smaller, hence the circuits *automatically detune themselves* and thereby keep down the currents. At the same time, the losses in the iron increase rapidly as the currents become larger, hence the effective resistances also become larger, and this also tends to limit the values of the current. It is a physical impossibility, therefore, to keep the circuits in tune or to keep the resistances very low; the practical operation of the Goldschmidt alternator is thus accounted for.

The Pupin theory shows that by suitably controlling the impedances $Z_1$, $Z_2$, $Z_3$, . . . . it should be possible to make any given amplitude larger than the others, but it also shows that to make the given amplitude large, the neighboring amplitudes must also be large. Professor Pupin long ago pointed out the possibilities in this method of generating radio frequency currents, but in his opinion the difficulties and disadvantages outweighed the advantages to such an extent that he did not attempt to develop the method for practical purposes.

Thruout this paper, attention has been confined to the case of a constant e. m. f. impressed on the stator. It should be mentioned, however, that the Pupin theory includes the case where the impressed e. m. f. is any function of the time. In conclusion it should also be mentioned that Professor Pupin showed his solution of the fundamental differential equations to Professor Moulton of Chicago University, and that the latter has since applied the method to the general theory of linear differential equations with harmonic coefficients.

SUMMARY: The case of a simple circuit having periodically varying inductance is first examined. The solution shows that the current has a constant component and an infinite series of convergently diminishing higher harmonics. Circuits having inductance, resistance, and variable mutual inductance are next considered. To solve the equations obtained, an infinite transformation is carried out, each variable being replaced by the sum of an infinite series of new variables, thus enabling an infinite number of arbitrary conditions to be imposed. As a result, an infinite series of equations is obtained, each of which can be solved if those preceding it have been solved. The solutions are worked out to the fourth harmonic in one circuit and the third in the other. In one circuit, only odd frequencies appear; in the other, only even. The general solutions are in the form of a Fourier's series, each amplitude of which is an infinite series. The convergence of the solutions is completely established. The solutions are then extended to the case where rotor and stator circuits contain capacities.

It is shown that according to Pupin's theory, all currents in low resistance rotors and stators tend toward infinity if these circuits are appropriately tuned. This apparent discrepancy from practice is explained on the ground that the variable permeability of the iron in the Goldschmidt alternators automatically detunes the circuits and that the increasing losses of the iron tend further to limit all currents.

# DISCUSSION

**Louis Cohen** (by letter): Aside from the interesting solution of the problem that the paper deals with relating to radio frequency alternators, the great importance of the paper consists in the general method that Professor Pupin has given us for solving differential equations having variable coefficients. I believe the method will prove of great value in the solution of many other problems in electrotechnics.

I recall that I have discussed this problem with Professor Pupin about six years ago, and he told me then that he had marked out the general solution of the problem, but reserved its publication for some future time. We ought to be grateful to Mr. Liebowitz for having put it in shape for publication and presenting it before the Institute.

As an illustration of the applicability of the method developed in the paper to the solution of other problems, it may be of interest to mark out the problem of the microphone circuit.

We have in this case an inductance, a variable resistance and a continuous e. m. f. in the circuit, and the circuit equation is,

$$L\frac{dI}{dt} + RI + rI\cos\omega t = E, \tag{1}$$

where R+r is the total resistance of the circuit in stationary condition.*

As far as I know the complete solution of this problem has never been given. Following, however, the method developed by Professor Pupin, we can readily obtain the solution of the problem.

Put $$I = I_o + I_1 + I_2 + I_3 + \ldots\ldots + I_n, \tag{2}$$

and make the substitution in equation (1), we get

$$\left.\begin{aligned} &L\frac{dI_o}{dt} + RI_o + rI_o\cos\omega t \\ &+ L\frac{dI_1}{dt} + RI_1 + rI_1\cos\omega t \\ &+ L\frac{dI_2}{dt} + RI_2 + rI_2\cos\omega t \\ &+ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot \\ &+ L\frac{dI_n}{dt} + RI_n + rI_n\cos\omega t = E \end{aligned}\right\} \tag{3}$$

* (R is the constant resistance of the external circuit; the resistance of the microphone, which varies periodically under the influence of a sound of frequency $\frac{\omega}{2\pi}$, is $r\cos\omega t$. The term $I\,(r\cos\omega t)$ in equation (1) is therefore the drop of potential at time t across the microphone.—EDITOR.)

In accordance with the method given in the paper, we can break up equation (3) into a number of independent equations, as follows:

$$\left.\begin{array}{ll}
\text{(a)} & L\dfrac{dI_0}{dt} + RI_0 = E \\
\text{(b)} & L\dfrac{dI_1}{dt} + RI_1 + rI_0\cos\omega t = 0 \\
\text{(c)} & L\dfrac{dI_2}{dt} + RI_2 + rI_1\cos\omega t = 0 \\
\text{(d)} & L\dfrac{dI_3}{dt} + RI_3 + rI_2\cos\omega t = 0 \\
 & \cdots\cdots\cdots\cdots \\
 & \cdots\cdots\cdots\cdots
\end{array}\right\} \quad (4)$$

Disregarding the transients, we have for the solution of (4a),

$$I_0 = \frac{E}{R}. \qquad (5)$$

Substituting the value of $I_0$ from (5) into (4b), we get

$$L\frac{dI_1}{dt} + RI_1 = -\frac{Er}{R}\cos\omega t \qquad (6)$$

and

$$I_1 = -\frac{Er}{RZ_1}\cos(\omega t - \theta_1) \qquad (7)$$

$$Z = \sqrt{L^2\omega^2 + R^2}, \quad \theta_1 = \tan^{-1}\frac{L\omega}{R}.$$

Substituting the value of $I_1$ into (4c), we have

$$L\frac{dI_2}{dt} + RI_2 = \frac{Er^2}{RZ_1}\cos(\omega t - \theta_1)\cos\omega t$$
$$= \frac{Er^2}{2RZ_1}\left\{\cos(2\omega t - \theta_1) + \cos\theta_1\right\}$$

and

$$I_2 = \frac{Er^2}{2RZ_1Z_2}\cos(2\omega t - \theta_1 - \theta_2) + \frac{Er^2\cos\theta_1}{2R^2Z_1}. \qquad (8)$$

Repeating the operation, we find in a similar manner,

$$\begin{aligned}
I_3 = &-\frac{Er^3}{4RZ_1Z_2Z_3}\cos(3\omega t - \theta_1 - \theta_2 - \theta_3) \\
&-\frac{Er^3}{4RZ_1^2Z_2}\cos(\omega t - 2\theta_1 - \theta_2) \\
&-\frac{Er^3}{2R^2Z_1^2}\cos\theta_1\cos(\omega t - \theta_1)
\end{aligned} \qquad (9)$$

$$
\left.\begin{aligned}
I_4 = {} & \frac{E r^4}{8 R Z_1 Z_2 Z_3 Z_4} \cos(4\omega t - \theta_1 - \theta_2 - \theta_3 - \theta_4) \\
& \qquad + \frac{E r^4}{8 R Z_1 Z_2^2 Z_3} \cos(2\omega t - \theta_1 - 2\theta_2 - \theta_3) \\
& + \frac{E r^4}{8 R Z_1^2 Z_2^2} \cos(2\omega t - 2\theta_1 - 2\theta_2) \\
& \qquad + \frac{E r^4}{8 R^2 Z_1^2 Z_2} \cos(2\theta_1 + \theta_2) \\
& + \frac{E r^4}{4 R^2 Z_1^2 Z_2} \cos(2\omega t - \theta_1 - \theta_2) + \frac{E r^4 \cos^2\theta_1}{4 R^3 Z_1^2}.
\end{aligned}\right\} \quad (10)
$$

and similarly for the other components.

If we collect separately the terms of the same frequency, and denote the results by $\eta_o$, $\eta_1$, $\eta_2$, etc., respectively, we get

$$
\begin{aligned}
\eta_o = {} & \frac{E}{R} + \frac{E r^2 \cos\theta_1}{2 R^2 Z_1} + \frac{E r^4}{8 R^2 Z_1^2 Z_2} \cos(2\theta_1 + \theta_2) \\
& \qquad + \frac{E r^4 \cos^2\theta_1}{4 R^3 Z_1^2} + \cdots \\
= {} & \frac{E}{R}\left\{1 + \frac{r^2}{2 R Z_1}\cos\theta_1 + \frac{r^4}{8 R Z_1^2 Z_2}\cos(2\theta_1 + \theta_2)\right. \\
& \qquad \left. + \frac{r^4 \cos^2\theta_1}{4 R^2 Z_1^2} + \cdots \right\} \quad (11)
\end{aligned}
$$

$$
\begin{aligned}
-\eta_1 = {} & \frac{E r}{R Z_1}\left\{\cos(\omega t - \theta_1) + \frac{r^2}{4 Z_1 Z_2}\cos(\omega t - 2\theta_1 - \theta_2)\right. \\
& \qquad \left. + \frac{r^2}{2 R Z_1}\cos\theta_1 \cos(\omega t - \theta_1) + \cdots \right\} \quad (12)
\end{aligned}
$$

$$
\begin{aligned}
\eta_2 = {} & \frac{E r^2}{2 R Z_1 Z_2}\left\{\cos(2\omega t - \theta_1 - \theta_2) + \frac{r^2}{4 Z_2 Z_3}\cos(2\omega t - \theta_1 - 2\theta_2 - \theta_3)\right. \\
& \qquad + \frac{r^2}{4 Z_1 Z_2}\cos(2\omega t - 2\theta_1 - 2\theta_2) \\
& \qquad \left. + \frac{r^2}{2 R Z_1}\cos(2\omega t - \theta_1 - \theta_2) + \cdots \right\} \quad (13)
\end{aligned}
$$

. . . . . . . . . . . . . . . . . . . . . . . . .

The total current in the circuit is

$$
I = \eta_o + \eta_1 + \eta_2 + \cdots \quad (14)
$$

It is seen therefore that the current is of a complex character, having a continuous current component, and currents of frequencies $\frac{\omega}{2\pi}$, $\frac{2\omega}{2\pi}$, etc. It is also to be noted that the amplitudes of the different components decrease as the frequencies increase.

As a partial proof we may consider the case when there is no inductance in the circuit, $L = 0$, we have then

$$
\begin{aligned}
\theta_1 = \theta_2 = \theta_3 = \cdots &= 0 \\
Z_1 = Z_2 = Z_3 = \cdots &= R.
\end{aligned}
$$

Equations (11), (12), and (13) reduce to

$$\begin{aligned} \eta_0 &= \frac{E}{R}\left\{1 + \frac{r^2}{2\,R^2} + \frac{r^4}{8\,R_4} + \frac{r^4}{4\,R^4} + \cdots\cdots\right\} \\ -\eta_1 &= \frac{E\,r}{R^2}\cos\omega\,t\left\{1 + \frac{r^2}{4\,R^2} + \frac{r^2}{2\,R^2} + \cdots\cdots\right\} \end{aligned} \tag{15}$$

. . . . . . . . . . . . . . . .

If we put L=0 in equation (1) we get

$$I = \frac{E}{R + r\cos\omega\,t} = \frac{E}{R}\left\{1 + \frac{r}{R}\cos\omega\,t\right\}^{-1}. \tag{16}$$

Expanding the above by the binomial theorem, we have

$$I = \frac{E}{R}\left\{1 - \frac{r}{R}\cos\omega\,t + \frac{r^2}{R^2}\cos^2\omega\,t - \frac{r^3}{R^3}\cos^3\omega\,t + \cdots\cdots\right\} \tag{17}$$

$$\cos^2\omega\,t = \frac{1}{2} + \frac{1}{2}\cos 2\,\omega\,t$$

$$\cos^3\omega\,t = \frac{1}{2}\cos\omega\,t + \frac{1}{4}\cos\omega\,t + \frac{1}{4}\cos 3\,\omega\,t$$

$$\cos^4\omega\,t = \frac{1}{4} + \frac{1}{2}\cos 2\,\omega\,t + \frac{1}{8} + \frac{1}{8}\cos 4\,\omega\,t$$

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Making these substitutions, we get

$$\begin{aligned} \because\ I = \frac{E}{R}&\left\{1 + \frac{r^2}{2\,R^2} + \frac{r^4}{4\,R^4} + \frac{r^4}{8\,R^4} + \cdots\cdots\right\} \\ &- \frac{E\,r}{R^2}\cos\omega\,t\left\{1 + \frac{1}{2}\frac{r^2}{R^2} + \frac{1}{4}\frac{r^2}{R^2} + \cdots\cdots\right\} \\ &+ \cdots\cdots\cdots\cdots \end{aligned} \tag{18}$$

The results by the two methods are in exact agreement.

**Benjamin Liebowitz** (by letter): Owing to the fact that Pupin's series diverge when tuned condenser circuits of low resistance are employed, great care must be exercised in interpreting the theory as applied to the Goldschmidt alternator. The theory shows that if a current of a given frequency is large, the currents of neighboring frequencies must also be large; but it also shows that by properly controlling the impedances (detuning some of the circuits, if necessary) *the series for a given frequency can be made to diverge more rapidly than any other.* There is nothing in the theory, therefore, which says that a high efficiency is impossible. On the other hand, a high efficiency would hardly be expected, owing to the inevitable large losses in the iron, and in practice the efficiency is not more than fifty-four per cent., according to Mr. Mayer.

It has been remarked that the currents of frequency $\frac{2\omega}{2\pi}$, for example, generated in the stator by successive "reflection" from the rotor, being of opposite signs, tend to neutralize each other. It must be borne in mind, however, that any power series whose ratio is greater than unity is divergent, even if the signs alternate. Therefore, all the currents tend toward infinity in an ideal machine, in spite of the differences in sign of successive amplitudes. The series will begin to converge only when the ratios $\frac{\omega M}{Z}$ become sufficiently small, and in tuned condenser circuits this cannot happen until the currents attain sufficiently large values to produce detuning, a decrease in M, and increases in the effective resistances, by the approach of saturation.

**Lester L. Israel** (by letter): From the theory developed in this paper it appears that currents of lower frequency due to reactions of the higher harmonics become increasingly large.

Since in practice the Goldschmidt alternator is quite efficient, this can hardly be so. Perhaps the apparent discrepancy may be accounted for by the fact that these induced lower harmonics are opposed in phase, together with a limitation or modification of the series representing them arising from the high energy absorption at one of the higher harmonics.